Chapter 11 Summary of Conclusions

Risks to health associated with ionising radiation have been overestimated by a wide margin. This conclusion has been reached bringing together three sources of scientific information: firstly a century of clinical experience of radiotherapy; secondly the current knowledge of radiobiology based on laboratory studies; thirdly the analysis of the long-term health records of large populations of people exposed to radiation, either as a single (acute) dose or as a continuing (chronic) one. The result is that new safety levels for human radiation exposures are suggested: 100 millisievert in a single dose; 100 millisievert in total in any month; 5,000 millisievert as a total whole-of-life exposure. These figures are conservative, and may be debatable within factors of two, but not ten.

There are three reasons why existing radiation safety standards have been set at levels that are typically a thousand times more cautious: firstly the association in the public mind of radiation with the dangers of nuclear weapons; secondly the advice of authorities, set up with a narrow remit to minimise public exposure to radiation and to satisfy the public aspiration for safety and reassurance; thirdly the 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 supportable. The evidence that workers exposed to radiation have 15–20% lower mortality from cancer before age 85 suggests that low doses of radiation might be beneficial.

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 additional fresh water. For this to happen rapidly, cheaply and without disruption, the public perception of ionising radiation needs to be turned around, and substantial changes in regulations and working practices, based on new safety levels, determined afresh. For the future, improved biological understanding may be able to justify relaxing safety levels still further, and legislation and working practices should be drawn up, 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, can be seen in a better light.

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

Epilogue: Fukushima

Instability and self destructioni

There is a legend in English folklore about Canute, a wise king of England and Scandinavia (1016-1035). His flattering courtiers told him that he was '*So great, he could command the tides of the sea to go back*'. But he knew his own limitations -- even if his courtiers did not -- so he had his throne carried to the seashore and sat on it as the tide came in, commanding the waves to advance no further. When they did not, he had made his point that, though the deeds of kings might appear great in the minds of men, they were as nothing in the face of nature. As with the sea, so with radiation; it is nature and science that determine the effect of radiation and its safety, not political authority. Just following safety regulations is no substitute for achieving some understanding.

On 11 March 2011 a magnitude-9 earthquake struck the north-east coast of Japan and generated a tsunami that completely devastated a wide coastal area. The death toll was 15,247 with 8,593 missing (as at 27 May) and over 100,000 properties were completely destroyed [62]. All eleven nuclear reactors at four nuclear power plants in the region that were operating at the time of the earthquake immediately shut down exactly as designed. In the aftermath of the subsequent tsunami three nuclear reactors at the Fukushima Daiichi plant destroyed themselves and released radioactive material into the environment. The accident was declared to be 'severity 7', the maximum on the nuclear accident scale, the same as Chernobyl -- but Chernobyl was quite different; its reactor was not shut down, there was no containment structure to inhibit the spread of radioactivity and the entire reactor core was exposed to the open air with a graphite fire that burned and contributed further heat to 'boil off' and send all volatile material high into the atmosphere.

So what happened to these reactors at Fukushima [63]? The description 'shut down' means that the neutron flux was reduced to zero and all nuclear fission ceased. Although there was never any risk of a nuclear fission explosion -- a nuclear bomb -- heat continued to be produced by radioactive decay, initially at 7% of full reactor power and falling to ½% within a day. This 'decay heat' is a feature of every fission reactor, as described in Fig. 22, and the Fukushima reactors were provided with many ways to disperse this heat without releasing radioactivity into the environment. At the time of the accident the tsunami deprived the reactors of power -- connections to the electrical utility were severed, emergency diesel generators were flooded and back-up batteries were exhausted after a few hours. As a result the cooling systems failed and the reactor cores became too hot and started to melt. In addition the pressure in the reactor containment vessels rose beyond their design strength. To prevent complete rupture it was necessary to reduce this pressure by venting steam including some volatile radioactive material, largely iodine and caesium. The released gas also included some hydrogen which exploded (chemically) in the air, blowing the roof off the outermost cladding of the buildings and hurling some contaminated debris around the plant and its neighbourhood. However, it would seem that these explosions did not involve any further release of activity as they were external to the primary containment vessel.

Of the dispersed radioactive elements, iodine-131 is known to be dangerous because it causes thyroid cancer if ingested by children who have not taken prophylactic iodine tablets. In Japan these tablets were made available, unlike at Chernobyl (see chapter 6). Since the activity of iodine-131 halves every eight days following cessation of nuclear fission, there was no iodine in the spent fuel ponds. Nevertheless the cooling of these storage ponds and their potential radioactive discharges have been an additional focus of attention. Radioactive caesium -- particularly caesium-137 which has a half-life of 30 years -- was released in significant quantities both at Fukushima and at Chernobyl. Outside the plant at Chernobyl there were no fatalities that can be attributed to radioactivity (other than iodine) and therefore none attributable to caesium. Indeed it is a curious fact that at Fukushima, in spite of the intense media interest in the radiation, while the tsunami killed thousands, the radiation killed none, and is unlikely to do so in the future. [After six weeks 30 workers had received a radiation dose between 100 and 250 milli-sievert [63]. At Hiroshima and Nagasaki 41 people contracted radiation-induced cancer in 50 years out of 5949 who received a dose in this range -- that is 1 in 150 (Table 5). At Chernobyl no emergency worker who received less than 2,000 milli-sievert died from Acute Radiation Syndrome (Fig. 9b).]

The powerful self destruction of the reactors at Fukushima has made arresting media headlines that have been closely followed by predictable promises of increased safety by the authorities. Modern reactor designs include more safety features than those at Fukushima and spending many millions of dollars on protecting a reactor against self destruction has always been a major element of its design and construction. But the record shows that human lives are far less at risk in nuclear than in conventional accidents -- at Windscale (0), Three Mile Island (0), Chernobyl (50) or Fukushima (0) than at Piper Alpha (167), Bhopal (3,800) or the Deepwater Horizon oil spill (11). The distinction would seem to be the simple legacy of fear associated with nuclear radiation. Distance is no barrier to alarm and fear; press reports of traces of activity from Fukushima detected as far away as Scotland, often failed to note the miniscule level found. Such reports sometimes have serious consequences; following Chernobyl, statistics for births in Greece published in the medical literature showed evidence for nearly 2,000 extra induced abortions attributed to the perceived threat [64]. Instead of spending large sums on appeasing fears by isolating people from radiation yet further in the name of safety, resources should be spent on real public education about nuclear radiation and its benefits for mankind.

Within days of the accident at Fukushima the media had exhausted their ability to described the size of the radiation threat, so spread panic rather than information. As a result many people fled Tokyo by plane and train. The cause was the fear that nuclear radiation engenders, rather than any knowledge of the radiation effect itself. Over-cautious radiation safety limits, enshrined in regulation in Japan as elsewhere, caused apparently incomprehensible information to be given by the authorities. For example, the Tokyo Electric Power Company (TEPCO), the electric utility company responsible for Fukushima, said that in the week of the 4 April it had released 10,400 tons of slightly contaminated water into the sea and that, although this contained 100 times the legal limit for iodine-131, this level would be safe, and that eating fish and seaweed caught near the plant every day for a year would add some 0.6 mSv to the dose above natural background [63]. These statements are probably true but their apparent mutual contradiction is a source for understandable alarm. This contradiction would not have occurred if the legal limits had been set to match a level As High As Relatively Safe (AHARS) instead of As Low As Reasonably Achievable (ALARA), a difference of a factor of 1000 or so.

However the story is not yet over and the task of containing the fuel and keeping it cool continues. Water, so essential to the cooling task, has become contaminated and must be filtered. Even with the use of robots the management of these tasks is daunting. Although the current position [4 June 2011] may not improve for some months yet, it is worth noting that at Chernobyl the fuel was open to the sky at high temperature so that the fate of the cooling water became irrelevant.

Much attention has been given to pointing a finger at who is to blame for the accident at Fukushima. For many TEPCO is seen as the villain. But I argue that this is unreasonable; those who live in Japan accept a very unstable geological environment. In the tsunami other buildings and plant were swept away completely, but the Fukushima Daiichi plant survived. It seems that the nuclear plant was able to withstand an earthquake well beyond its design and with a few changes it would have withstood the tsunami too, for instance, a better site, a higher sea wall and protected diesel generators. Indeed the other reactors in

Japan did so with little or no damage. With hindsight it is easy to find measures that could have been taken, but why should nuclear safety be treated as exceptional? Nobody died from failure of nuclear safety but they died in tens of thousands from failure of general protection against the effect of a tsunami, about which there is far less comment [66]. This blame game arises from a preference to pin responsibility on someone rather than to sit down and think carefully about what happened -- and whether a nuclear radiation incident is worse than a tsunami. In more stable parts of the world these natural forces represent no hazard to a nuclear plant in any event. However, irrational fear and a loss of trust in fellow human beings and the organisations for which they are responsible show the presence of instabilities in society, just as earthquakes show geologically unstable regions. International reactions to Fukushima have indicated that many countries suffer from such instability, whether through inadequate public education, uninformed political leadership or a lack of readiness among individuals to learn about the science that affects their lives. In every community a few members of society should find out and others should trust them. Mutual trust is essential for human survival and there is no reason to treat nuclear radiation safety as a special case.

Explanation or appeasement

A lack of public information and over-cautious radiation regulations, mis-interpreted as danger levels, caused widespread despair and misery at Chernobyl where the enforced evacuation at short notice of the local agricultural population to distant and unfamiliar accommodation was responsible for serious social damage; the consequences of this dislocation have been emphasised in recent reports [12]. The nuclear accident highlighted the fractures inherent in Soviet society and when Gorbachev reflected on the disaster it was the socio-economic earthquake of the end of the Soviet era that he saw. Abroad, the over-cautious regulations based on appeasing public opinion caused serious economic damage, as admitted, for instance, in the press by the authorities in Sweden in 2002 [28].

8 Epilogue: Fukushima

At Fukushima too there has been damage to families, communities and the economy caused by the evacuation on top of the destruction and death from the tsunami. The exposure level (20 milli-sievert per year) used to define the evacuation zone is too low and large numbers of people have been evacuated who should not have been displaced. The criterion for such invasive socio-economic surgery should be set relatively high, perhaps up to 100 milli-sievert per month, which is still some 200 times smaller than the monthly dose rate received by the healthy tissue of patients on a course of cancer therapy. Evidently concerns for human health based on ALARA are out of balance with concerns for human health applied in clinical medicine. At Fukushima, as at Chernobyl, the principal threat to health has come from fear, uncertainty and enforced evacuation, not from radiation. In Japan official caution about radiation has damaged many lives and generated extra socio-economic cost, misery, recrimination and loss of trust in authorities.

We need better public explanation and realistic safety standards. Currently these are set on the advice of the International Committee for Radiological Protection (ICRP) "*based on (i) the current understanding of the science of radiation exposures and effects and (ii) value judgements. These value judgements take into account societal expectations, ethics, and experience*" [65]. In the past ICRP has followed opinion rather than leading it, a mistaken approach given the state of popular understanding of radiation derived from the primitive picture left by last century's political propaganda. After Chernobyl the chairman of ICRP admitted that the approach of extra caution had failed (see final pages of chapter 6). The ICRP has been urged to revise its approach by academic national reviews [21,22] and others [41]. Accordingly, it should now show some leadership; safety levels should be revised in the light of modern radiobiology and supported with programmes of public re-education -- some in the community are quite bright and welcome reasoned explanation. The new levels should be as high as is relatively safe (AHARS) rather than as low as reasonably achievable (ALARA). For their sakes we need to educate young people for the dangers of the

21st century, not shackle them with the misunderstandings of the 20th. In a world of other dangers -- earthquakes, global warming, economic collapse, shortages of jobs, power, food and water -- the expensive pursuit of the lowest possible radiation levels is in the best interest of no one.