Presented at IChemE. Sustainable Nuclear Energy Conference
Manchester, 11 April 2014
Version 2 March 2014

More scientific appreciation, not more safety, is what nuclear needs today

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Keywords: Nuclear technology; radiation safety; biology; education; evolution; radiophobia

1. Introduction

The safety of nuclear radiation is thought to be a problem for physical science, but a century of experience of radiation biology demonstrates that life is well protected against the dangers of radiation by 1000 million years of evolution, so that, with re-education, mankind should see nuclear technology as cheap and welcome.

There are reasons why people might think that nuclear radiation is exceptionally dangerous:

- per kg of fuel, nuclear is a million times more energetic than the combustion of fossil fuel[1];
- ionising radiation cannot be consciously felt;
- since 1950s official international advice on nuclear radiation has recommended that only the lowest achievable dose levels should be considered safe (As Low As Reasonably Achievable, ALARA).[2]

However each of these is flawed.[3] Nuclear is exceptionally safe in theory and this has been confirmed in practice, not least by the accident at Fukushima.

The energy release in a nuclear explosion results in a powerful blast and fire in the immediate neighbourhood of the detonation but the longer term consequences of the associated radioactivity and radiation are less significant. Unlike fire which is spread by a thermal chain reaction, nuclear energy is confined within nuclei and mutual contact between these is ruled out by enormous electrical repulsion overcome only at the centre of the Sun. Otherwise the only way that more nuclear energy can be released is with neutrons. These are unstable and only exist in a working reactor or a nuclear weapon. Without neutrons nuclear radiation does not make anything radioactive, and radioactivity can only decay, but not propagate.

As a result nuclear technology is exceptionally safe, its extreme energy is contained and its use in civilian technology is almost without risk. The danger involved in the domestication of fire, and the environmental effects of chemical combustion generally, are much greater, although that decision when taken in prehistoric times, was crucial to the future of civilisation, see Figure 1. The decision to choose nuclear today is much easier to justify than was the decision to choose fire then.

Figure 1 The final confrontation with the Environmental Anti Fire Party 125,000 BC, perhaps

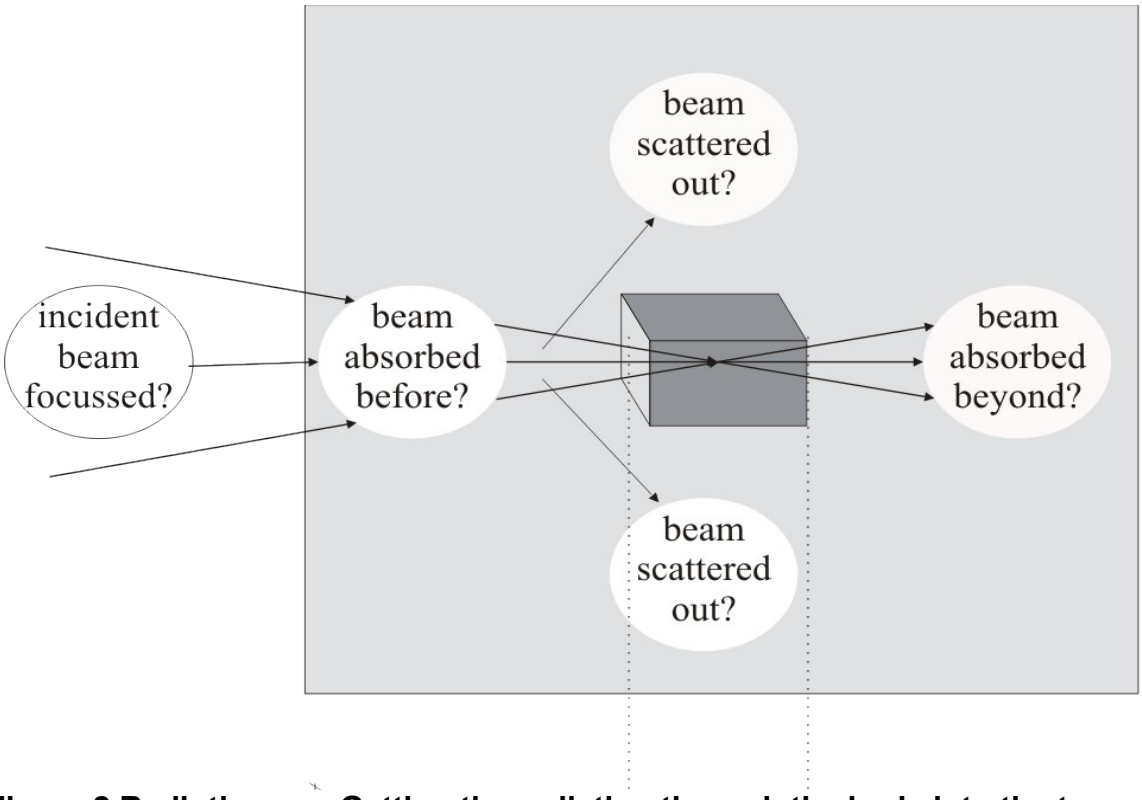

Figure 2 Radiotherapy. Getting the radiation through the body into the tumour (schematic)Tissue outside tumour gets 50% of the dose to the tumour

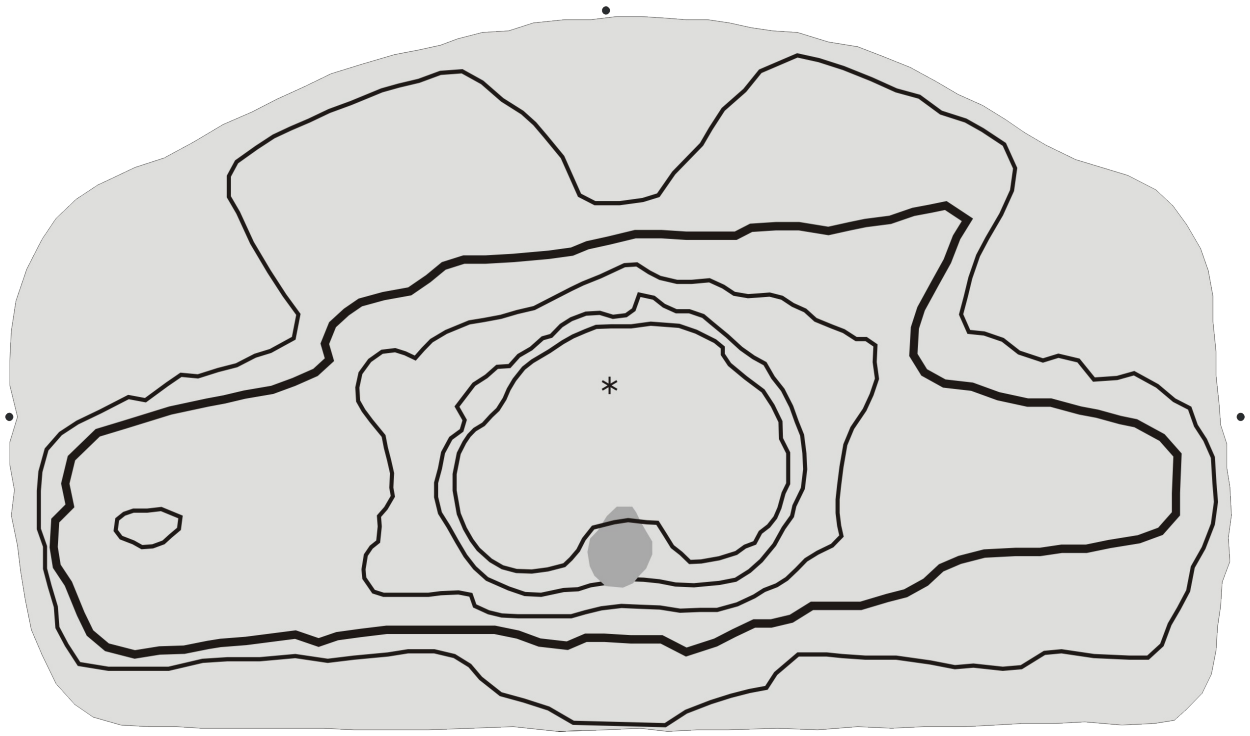

Figure 3. Radiotherapy dose contours of an actual prostate cancer treatment showing contours at 97, 90, 70, 50, 30% of peak dose. The section shows the lower abdomen perpendicular to the spine with the rectum shaded.

2. Radiation and radiotherapy

Radiation dose rates in excess of 40,000 mSv per month have been in use for over a century and accepted by the public to cure cancer under the aegis of Marie Curie. (The dose rates used can be found on the website of the Royal College of Radiologists.)[4] As shown in Figures 2 and 3 the energy deposited in therapy is not confined to the tumour that dies, and in a course of treatment nearby healthy tissue typically receives 20,000 mSv per month and yet survives with a risk of no more than 5% of contracting a new primary cancer. The radiation dose rates that patients receive usually benefit their health although these are 10,000 to 100,000 times larger than the ALARA limits (between 1 and 20 mSv per YEAR). That those limits make no sense is also confirmed by what happened at Chernobyl, Fukushima and in other accidents. Radiotherapy treatment is extended over several weeks to benefit from the multiple repair mechanisms that enable healthy tissue to recover from the effects of radiation. These are ignored in the ALARA safety prescription, although without them radiotherapy would be fatal.

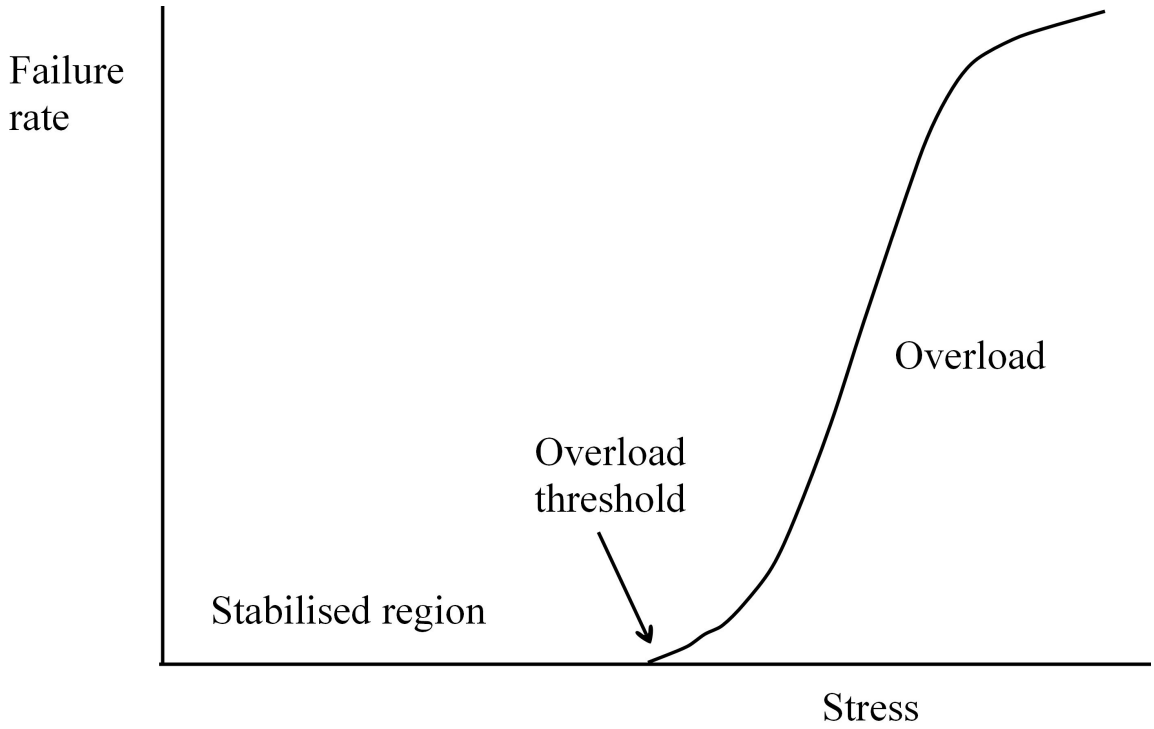

Figure 4. A typical stabilised response to a stress, as in an electronics or engineering context with characteristic overload threshold (response/feedback time not shown)

3. A radiation attack on life

Radiation energy is much more energetic than the energy that binds molecules, so that its effect is quite indiscriminate and most materials are affected in a similar way. The initial damage is broadly in proportion to the radiation energy absorbed, but that is not true for subsequent effects in living tissue. What happens to life depends on damage to DNA – all other molecules can be replaced by reference to DNA as the master "drawings". Since water makes up over 50% of tissue, the dominant products of a radiation attack are fragments and ions, H, OH etc, and these then oxidise DNA. The same oxidants are produced more prolifically in normal metabolic processes including physical exercise and mental activity.[5] It is the business of biology to stabilise life against attack by these oxidants wherever they come from as suggested in Figure 4. In 1000 million years evolution has provided overlapping mechanisms of protection through feedback, repair and replacement. Like any stabilisation, it is effective for low and moderate stresses, but fails above a certain threshold and describes a non linear response -- unlike the standard so-called Linear No-Threshold model (LNT) that is used in the attempt to underpin ALARA. Each mechanism takes a time to act and it is the stress within this time that may exceed a threshold for long term damage. Mechanisms are based on inherent design (eg multi-cellular structure with many DNA copies), active response to attack (eg repair and replacement of cells) and adaption in the light of previous attacks (eg provision of extra resources for repair and enhanced immune response)[6]. Below threshold there is no permanent damage but often some benefit in the form of adaption to further attack. This smart real-time safety provision, evolved gradually for the benefit of all cellular life from amoebe to cabbages and then to humans is not conscious and is superior to modern attempts at conscious regulation-based protection (ALARA). The effectiveness of this is described in Figure 5.

Figure 5. *As Aesop's Fable of the Tortoise and the Hare illustrates*
the natural protection of life, eg from ionising radiation, provided by slow evolution wins easily against regulation determined by committee

What happens if the threshold of lasting damage by radiation is exceeded? In the short term the repair and replacement mechanisms may be overwhelmed, the cell cycle suspended and the extent of cell death may involve the death of the organ or whole organism. This is death by Acute Radiation Syndrome within a few weeks of the attack and is unrelated to cancer.

In the longer term rogue or cancerous cells may start to multiply depending on the vigilance of the immune system. This declines with age and so cancer afflicts the elderly in particular. For this reason it can take some years after a radiation exposure for a delayed cancer to become established. The public are naturally upset by the incidence of such cancers and also by any possibility of radiation-induced genetic modification that might be handed down to later generations although no case of this has ever been established in humans

4. An example, ultraviolet

A good example of how life responds to ionising radiation is the response to ultraviolet (UV) radiation. Figure 6 illustrates the spectrum of electromagnetic radiation. Visible light lies in the centre with its rainbow colours. To the right with longer wavelengths are infra-red, microwaves and radio waves that cannot damage life except through heating. To the left of light are the more powerful forms of radiation that can break molecules: ultraviolet, X-rays and gamma rays. UV is present in sunshine and its danger is known to the public. As for other forms of ionising radiation the damage caused to living tissue is usually corrected in a day or two -- the cell death when layers of skin peel off that all know as sunburn. UV can also cause skin cancer years later and this is often fatal if not treated. The main difference from X-rays and other radiation is that UV does not penetrate far through the skin but is no less dangerous for that.[7] However public attitudes to UV in

sunshine are reasonably informed and not given to worldwide panic. As illustrated in Figure 7 sensible advice is available from the local pharmacy or doctor. not a committee of the United Nations!

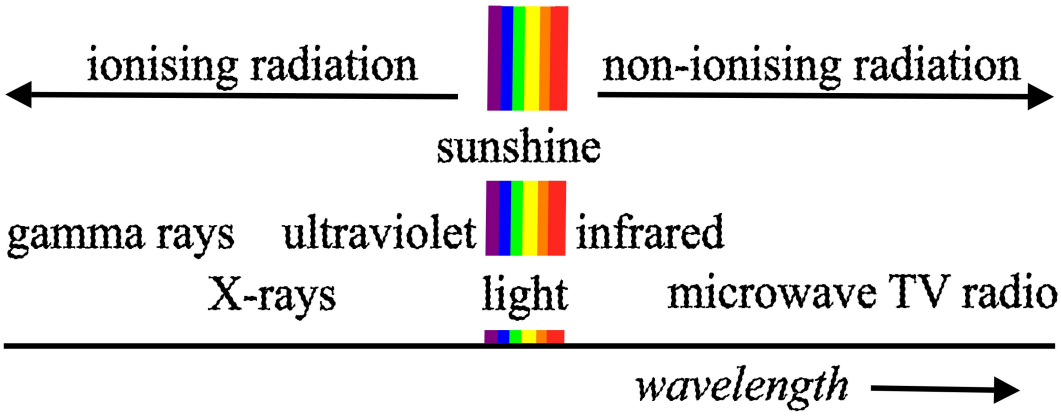

Figure 6. The electromagnetic spectrum (simplified)

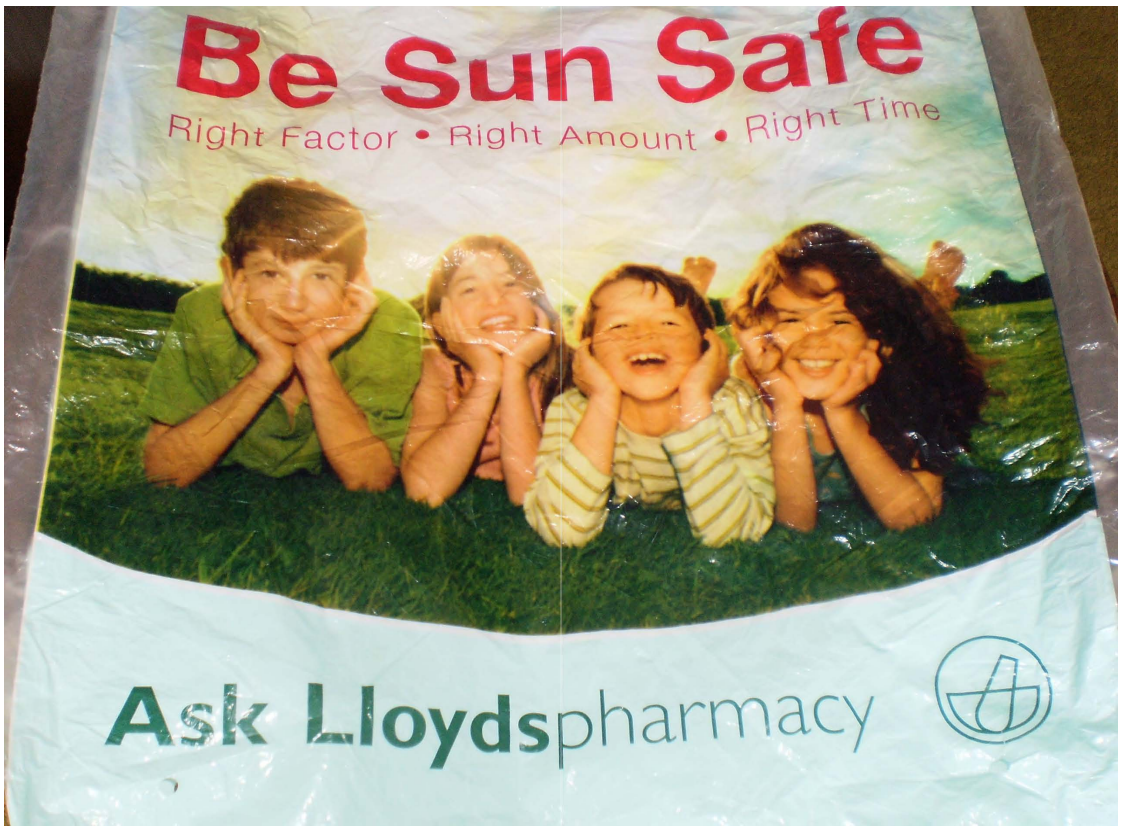

Figure 7. *Living, loving and laughing with UV radiation.* **A shopping bag showing a sensible attitude to UV radiation -- although it is far from danger-free.**

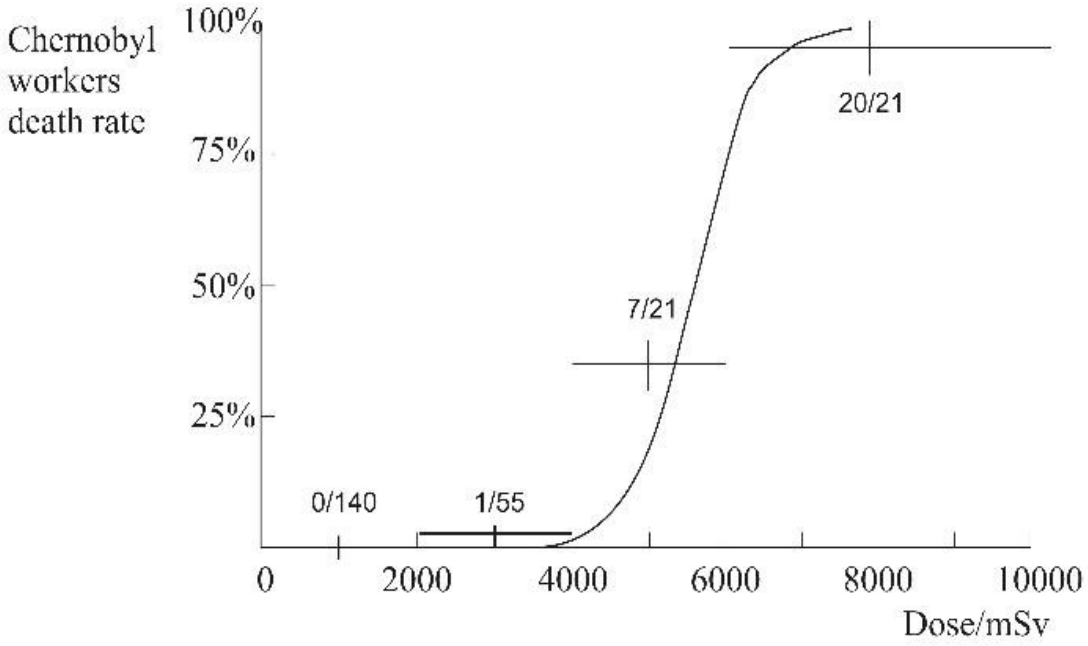

Figure 8. Mortality of early fire fighters at Chernobyl (crosses) as a function of dose, shown as ARS death/total. The curve is for rats.

5. Chernobyl

At Chernobyl some 237 workers were affected when they made early sorties to dowse the reactor fire. As shown in Figure 8, of these, 28 died from ARS within a few weeks. The doses they received and the corresponding mortality rates are shown by the crosses on the diagram. The curve comes from similar data for rats exposed in the laboratory. These are in fair agreement and follow the type of behaviour expected for a stabilised response. They suggest a threshold for an acute dose of 2000 to 4000 mSv. Since the Chernobyl accident there has been no evidence for any extra cancer cases among the survivors attributable to their radiation exposure, although there have been additional cases of thyroid cancer among children in the region with iodine deficient diet. Most of these were treated successfully but 15 died. These figures are quite modest for what has been described as the worst-ever nuclear accident with a reactor of unsafe design. The social stress created by Chernobyl was serious and widespread, exemplified by alcoholism and family breakup locally among evacuees,[8] and by high abortion rates[9] and unwarranted food destruction further afield in Europe.[10]

6. Goiania

In 1987 in Goiania, Brazil, a caesium-137 radiotherapy source of 10TBq, so 10 million million Bq, fell into the hands of some scrap merchants and their families.[11] They broke it open -- it glowed with an enticing blue light and children painted themselves with it, spreading it around their home and kitchen, and their neighbours were invited in to see

and admire. When finally resolved, 249 people had been contaminated, internally or externally. Four died of ARS including a girl with a measured internal radioactivity of 1000 million Bq. In addition, 28 had serious burns requiring surgery. Since the accident two babies were born to women with very high internal dose, one with 0.2 million Bq who was pregnant at the time of the accident and another with 300 million Bq who gave birth 3 years 8 months later. No problem with the births has been reported. Their activity is shown in Figure 9. Now, after 25 years the total number of cancers reported with any possible link to the radiation is zero.[12] How can this be? Evidently the internal radioactivity that spread throughout their bodies and extended over many months was handled by the repair and adaptive responses. Although the statistics are few the doses are high, the data are human, fetuses and children are involved and the dose is internal – these are all considerations that cause special concern to the public.

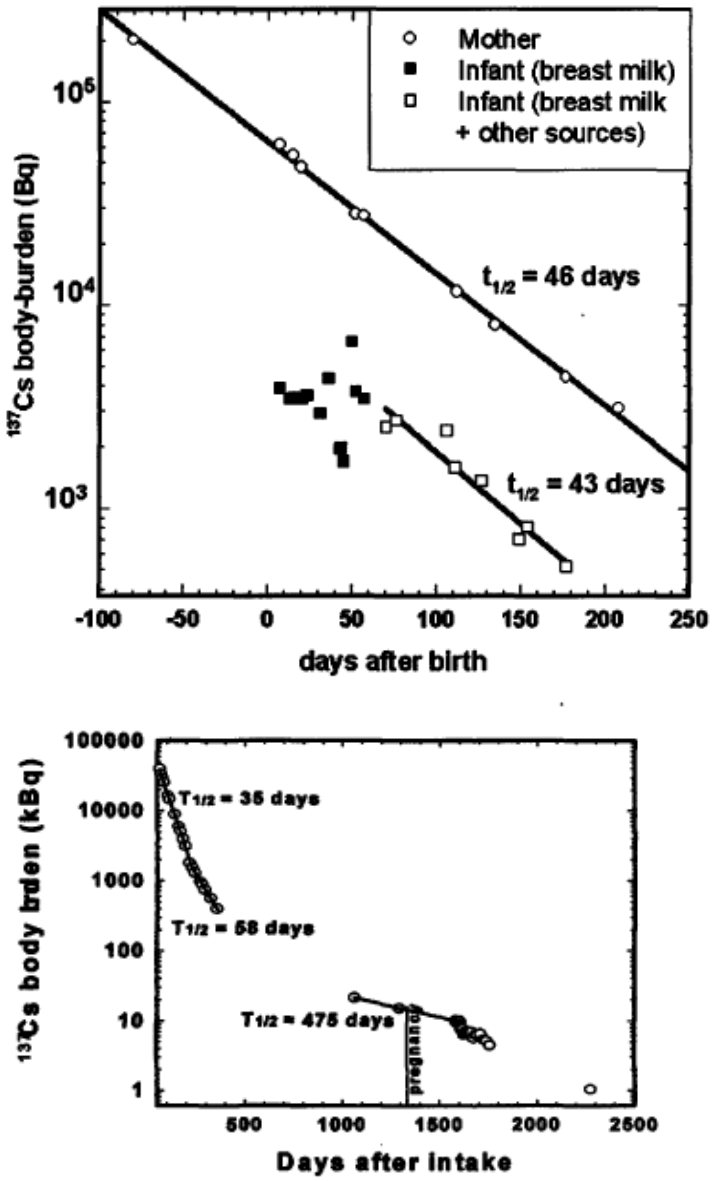

Figure 9. Upper plot. The measured decline of Cs-137 radioactivity for a mother and child irradiated 4 months before healthy delivery.
Lower plot. The same for a mother who had an activity of 300 million Bq and became pregnant 3 years 8 months later. A healthy outcome is also reported

7. Fukushima

In Japan the earthquake and tsunami of March 2011 killed 18,800 people, powered incidentally by the decay heat from the "natural" radioactivity in the Earth. It destroyed major infrastructure installations but no nuclear power plants; however the destruction of the auxiliary diesel generators at the Fukushima Daiichi plant caused the subsequent destruction of three reactors with a significant release of iodine-131 and caesium-137 into the environment, specifically the atmosphere and the reactor cooling water. Unlike for the quake and tsunami there was no public education in place to inform the population of the effect of a radioactive release. Unlike at Chernobyl there was much excited ill-informed reporting on the Web and this spread around the world. Almost nobody provided reassurance at the point when it was needed in the first days before opinions hardened[13] and the firestorm of ignorance swept on. The Fukushima nuclear accident cannot be called a disaster -- there was been no casualty from radiation and none is expected, as confirmed two years too late by WHO[14]. The worst effect of the radiation was some beta-burns on the feet and legs of workers who got their feet wet in a basement flooded by contaminated water. Whole body scans of the public revealed internal contamination by caesium-137 of less than 10^{-4} to 10^{-5} times what caused any mortality at Goiania.[15]

Figure 10. Ill judged public relations. Officials dressed up in protective clothing

However, instead of telling the public the reassuring truth the authorities panicked. Everything that they did reduced public confidence:

- In July 2011 they set a limit on food of 500 Bq per kg[16] – you would have to eat a ton of such food in 3 months to get a dose as large as a single CT scan;
- In April 2012 they lowered the limit to 100 Bq per kg, equivalent to eating 5 tonnes of food;
- On 4 April 2011 when TEPCO released 11,500 tons of water with 10^4 Bq per litre into the sea, they said that this was 100 times the limit but that it was quite safe[17]. Both statements are true. Instead of explaining they lost credibility. Drinking a litre of

such water every day for three months would be equivalent to two CT scans.

- They sent officials in protective clothing to dig up children's playgrounds. Such clothing simply frightens people appearing to confirm their worst fears.
- They shut down NPP pending safety improvements. To the public such work confirms that it was previously unsafe -- which in fact the tsunami had shown was untrue. The nuclear industry around the world did not act in its own or the public interest; it appeared to have lost confidence.
- They evacuated regions where the contamination was far below any level of risk, causing severe stress in the population – death among the elderly, alcoholism and family break up among the young and middle aged, and bedwetting and dis-orientation among children. Bankruptcies and over a thousand extra deaths, unrelated to radiation, have been reported.[18]

Meanwhile wildlife at Chernobyl thrives freed of the intrusive behaviour of man, albeit still radioactive [19]

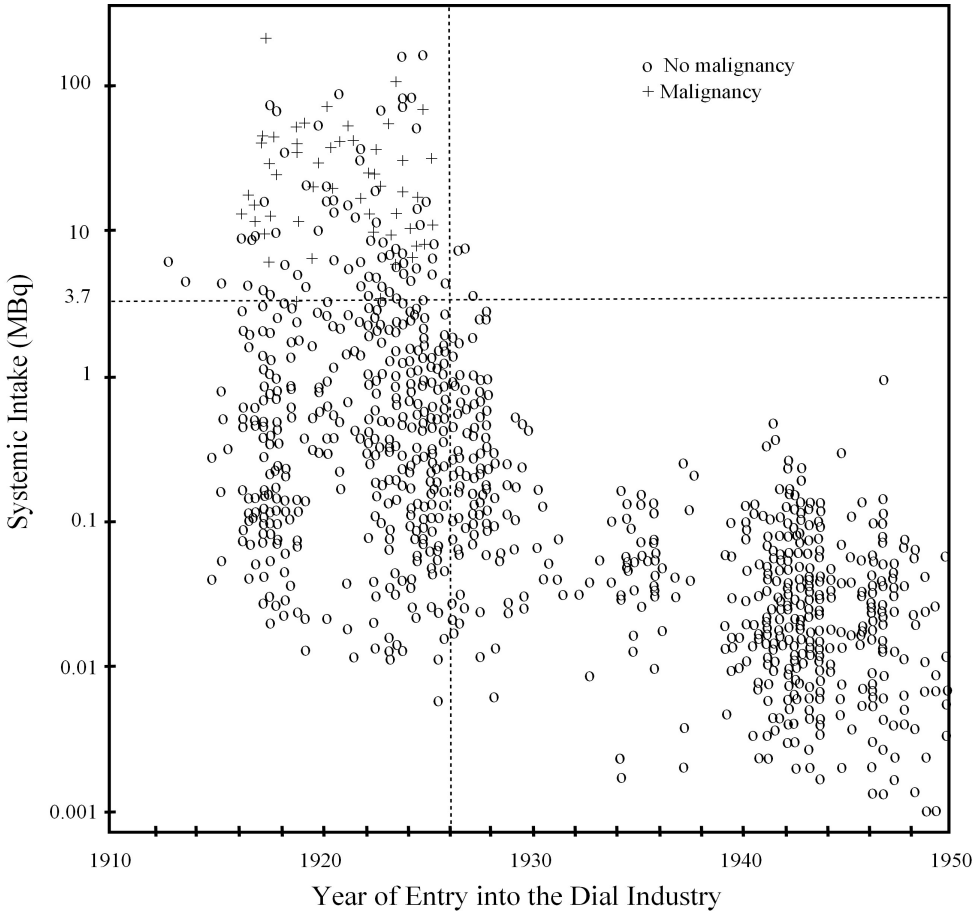

Figure 11 The radium dial painters. Death due to bone cancer is marked with a cross, others with a circle. There are no malignancies after 1926 and none with an intake of less than 3.7 million Bq.

8. Industrial safety

On the question of what chronic dose rate is hazardous, some of the clearest data come from the workers who painted dials with radium paint early in 20th Century, Figure 11[20] Those workers who licked their brushes to improve the fineness of their product contracted bone cancer. The practice was discontinued in 1926. Measuring their dose is relatively easy because of the long halflife of radium in bone. A clear threshold at 3.7MBq is seen corresponding to about 10,000 mGy as a lifelong chronic dose of alpha radiation.[21] Specifically, none of 1339 painters with less than 10,000mGy died of bone cancer [3 expected], but 46 died out of 191 with more than 10,000mGy [<1 expected].

Such a high threshold is not incompatible with observations from Goiania and primary cancers induced by radiotherapy. It is incompatible with ALARA standards and these routinely compromise normal standards of industrial safety -- according to reliable attributable reports, as shown in Figure 12. ALARA safety, intended to allay fears, achieves the opposite. Such regulation and worker stress drive up costs, bring no benefit to anyone and are economically damaging.

Radiation safety based on LNT+ALARA is quite incompatible with modern radiobiology [22] and patients try to avoid prescribed CT scans because they fear an increased risk of cancer.[23] A guiding principle for physicians is that, whatever the intervention or procedure, the patient's well-being is the primary consideration and this is being violated. The remedy for radiation fear is to discard politicized science which dates from the Cold War period and treat such radiation in the same way as UV which has no political edge. There is no case for a special Precautionary Principle – unlike climate change about which we are still learning, enough is known about nuclear radiation from a century of study.

(1) Ken Chaplin, senior inspector

"...working in a relatively high temperature environment in lead jackets and plastic lined suits. The radiological hazards ... insignificant,... we almost passed out from the heat in a very difficult to access location.

... ladders, with very little space to get their feet on rungs... required to wear steel toed shoes, inside rubber 'one size fits all' boots, inside paper booties.... in the name of contamination control; however, I am far more concerned about people falling 8 metres onto piping.

Staff are increasingly worried ... lower productivity ... higher stress levels ... entire organization pursuing ALARA, without ... health benefits.

... watching as radiological protection dogma, ALARA, stops the nuclear industry dead in its tracks. It is hard to prevent this, but I am trying."

(2) Howard Iskayn, design engineer

" a real hazard of death by the escape of hot gas. Regulator stated that ... not concerned with death by anything other than nuclear exposure.... 'death by hot gas was satisfactory so long as the body could be buried without radiation restrictions' "

Figure 12. Two attributable professional accounts of how ALARA is being used to override normal industrial safety

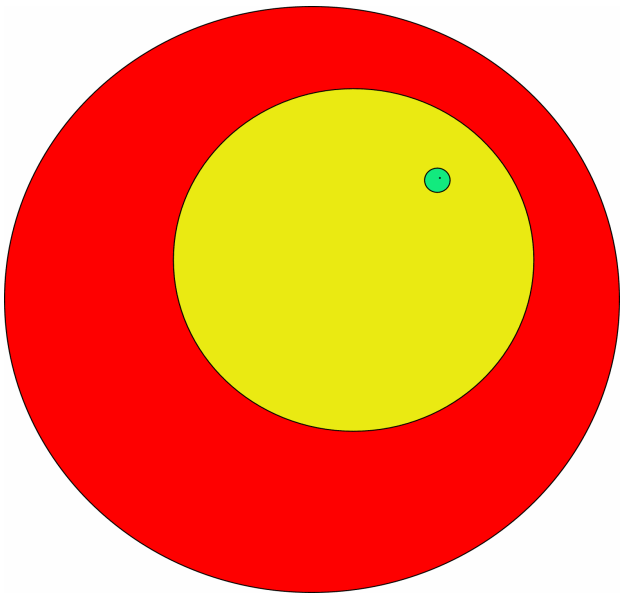

Figure 13. A comparison of monthly doses shown as areas.
RED 40,000mSv per month fatal dose to tumour cells in radiotherapy
YELLOW 20,000mSv per month non-fatal dose to healthy tissue in radiotherapy with few % chance of cancer
GREEN 100mSv per month conservative safe dose limit in any circumstance AHARS
BLACK dot in green 0.08mSv per month (1mSv/yr) public limit recommended by ALARA/LNT

9. Scientific safety limits

To find a safe threshold, monthly radiation doses are compared in Figure 13. This takes into account the repair and recovery that happens in that time in a conservative way – laboratory study and experience with radiotherapy show that most recovery is much faster. The radiotherapy doses received by patients kill tumours and prolong life. With an extra safety factor of 200 a limit of 100 mSv per month is sufficiently low that there is no record of damage to life at this or lower levels (As High As Relatively Safe, AHARS). This is 1000 times (or 50 times) higher than limits prescribed by current ALARA/LNT regulations.

The cost of these current regulations, the research that they engender and the working restrictions that go with them, apply punitive pressure on the financial viability of nuclear energy, although it is the only non-fossil base load technology available. With realistic AHARS levels concern about waste, decommissioning, dirty bombs, etc are all devalued. Given that perhaps half nuclear manpower is engaged in safety, decommissioning, waste management working practices etc the cost of nuclear might be reduced by 30% or even half.

10. The future

If global warming is severe, the future lives for our children and grandchildren will depend on our ability to convey, now before it is too late, the unambiguous and positive story that radiation is safer than the other dangers that beset us and that nuclear energy is essential. That requires new safety regulations, properly based in science and medicine and explained in full to re-establish trust and confidence, free from political manoeuvring and ill-informed media reports. An uninformed democracy is a loose cannon. The international authorities by hanging onto LNT and ALARA are in a hole and should stop digging. They should build trust, instead of trying to blind the public with the authority of expertise. They

should concentrate on science and education, especially biology, and appreciate that viable popular politics leads towards cheaper energy and health without fear. Industry should play its part in improving the nuclear image, for instance by realising that selling safety improvements has simply confirmed in the public mind that nuclear was not previously safe. First this is an international problem but if the nuclear industry does not strive towards a cheap and beneficial technology, responsive to the world's needs, then someone somewhere else will do so. Education and communication is cheaper and more effective than searching for a technical silver bullet.

Figure 14 ALARA/LNT safety is good for no one except fossil fuel interests

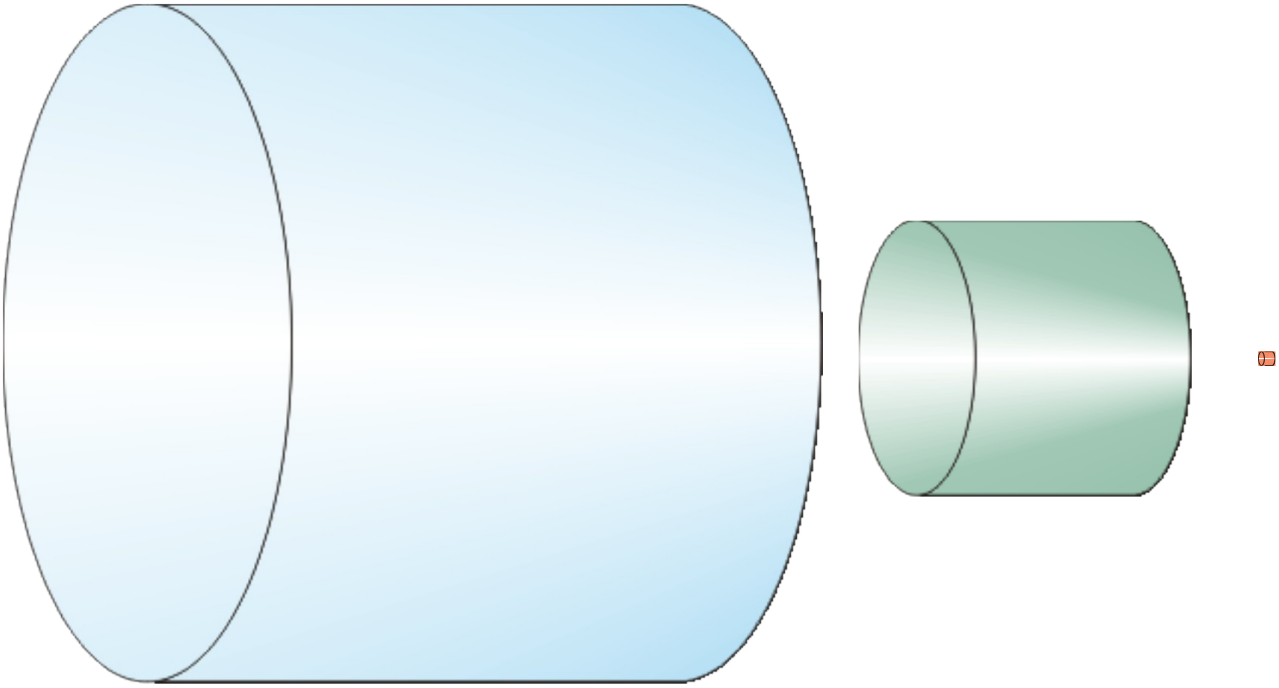

Figure 15 Waste per person per day shown by mass (UK) BLUE 30kg CO2 direct to the atmosphere. hundreds pf 0000s of deaths per year; GREEN 2 kg biological waste direct into the environment, millions of deaths per year by chain reaction; RED 1/4000 kg high level nuclear waste, buriable solid, less than 1 death per year

1 This factor comes directly from elementary Quantum Mechanics as the ratio of the kinetic energy of a proton or neutron confined in a nuclear volume to that of an electron confined in an atom.
2 UNSCEAR (UN Scientific Committee on the Effects of Atomic Radiation) and ICRP (International Commission for Radiological Protection). *Report 103: 2007 Recommendations.*. http://www.icrp.org
3 As discussed at greater length in *Radiation and Reason the Impact of Science on a Culture of Fear* Wade Allison (2009). See also www.radiationandreason.com for further editions and updates.
4 Although radiotherapy doses are usually quoted in mGy, these are the same as mSv for most practical purposes http://rcr.ac.uk/docs/oncology/pdf/Dose-Fractionation_Final.pdf
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8 UN Chernobyl Forum, WHO http://whqlibdoc.who.int/publications/2006/9241594179_eng.pdf
9 http://www.bmj.com/content/295/6606/1100.extract
http://library.temple.edu.libproxy.temple.edu/ - qt-homepage_search_tabs-ui-tabs2
10 As discussed in Chapter 6 of Reference 3
11 *The Radiological Accident in Goiania*, IAEA, http://www-pub.iaea.org/mtcd/publications/pdf/pub815_web.pdf and http://www-pub.iaea.org/MTCD/publications/PDF/te_1009_prn.pdf
12 N Valverde communication http://www.radiationandreason.com/uploads//enc_GoianiaValverdeVienna2013.pdf
13 An exception http://www.bbc.co.uk/news/world-12860842
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20 Rowland RE http://www.osti.gov/accomplishments/documents/fullText/ACC0029.pdf with comment (2004) http://www.rerowland.com/Dial_Painters.pdf
21 For slpha radiation 10,000 mGy is traditionally reckoned as 200,000 mSv, that is with a weighting factor of 20.
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