A Tragedy of Misunderstanding
there was no major radiation disaster at Fukushima

An invited talk at the Annual Meeting of the American Nuclear Society,
Chicago, 25 June 2012
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Summary

Low or moderate radiation doses are benign but the public health effects of fear and panic, caused by ignorance and over-cautious international "safety" standards, are dangerous, both to individuals and to the society and economy at large. A disaster of fear, not radiation, occurred at Fukushima as a result of the damage to the nuclear plant.

When the earthquake struck there were 500,000 people in the region subsequently inundated by the tsunami and within 26 to 45 minutes, all except 18,880 had managed to escape, a truly remarkable achievement. The training and understanding of the Japanese people that was evident for the tsunami was absent for the release of radiation and radioactivity. Faced by an unknown threat, nobody knew what action to take, and few in authority knew either, so that rumour and panic, extending to the highest levels, lead to serious social harm, widespread voluntary evacuation, failed businesses and losses of confidence in society and nuclear power. This failure of society to cope with an accident, for which no loss of life should be expected, is strange. Fear of powerful energy is a protective animal reaction, but man has survived dangers through study, understanding and mutual organisation -- although not in the case of radiation and radioactivity. Why not?

Nuclear and its associated radiation are indeed powerful, a million times more energetic than chemistry, simply because the kinetic energy of a nucleon confined inside a nucleus is a million times greater than that of an electron trapped in an atom, as described by elementary quantum mechanics. But this energy is physically safe because nuclei never meet, well almost never. Since the Earth was formed only one nucleus in a million has changed at all, and then only by decay. Nuclear decay is safer than fire or biological hazards; it cannot spread by contagion, it leaves little waste, most often solid, and it eventually diminishes, unlike chemical wastes. Otherwise, fresh nuclear energy can only be released on Earth through the effect of neutrons that are unstable and do not exist except inside a working nuclear reactor. It is difficult to imagine that nuclear energy could possibly be safer, physically. But what happens when radiation meets living tissue?

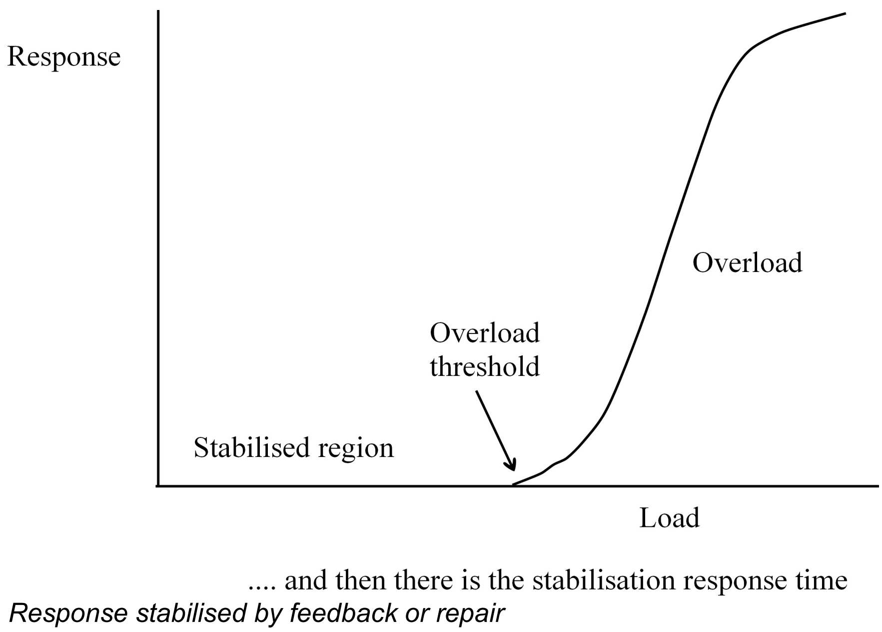

Figure 1. Response stabilised by feedback or repair

Biological molecules are delicate and seemingly at the mercy of ionising radiation, but they are also at the mercy of more mundane chemical oxidation. Unsurprisingly, biology, dedicated to the survival of life, has evolved many repair and servicing mechanisms whose function is to stabilise life against these attacks. The simpler of these are now understood by biologists, others are being slowly unravelled, including the action of the immune system. Like any feedback or repair system it takes a time to respond and is particularly vulnerable to being overwhelmed by high radiation doses accumulated within this time. However, at longer times departures from stability are not generally cumulative. Like their engineering analogues, such mechanisms are intrinsically non-linear, that is non-additive.

The verification of this picture, the determination of radiation-induced failure modes, the characteristic times and failure thresholds are matters particularly for human data including clinical experience and the result of accidents.[1] The data relate, either to acute doses for which there is no time for repair to play a role, or to chronic and protracted doses which are spread in time and benefit from stabilisation. It was established long ago that there are two basic failure modes:

- cell death and Acute Radiation Syndrome (ARS) at high doses in which cells fail and resources are not available to replace them - this may cause death with high probability on the timescale of a cell cycle for important cells, a few weeks at most;
- damage to DNA that is not repaired or suppressed by the immune system, possibly leading to cancerous growth. This appears later in life, possibly when the immune system is less active. Radiation is only a minor additional cause of cancer, the contribution of which can only be distinguished statistically. 95% of the survivors of Hiroshima and Nagasaki who died of cancer between 1950 and 2000 would have done so anyway.

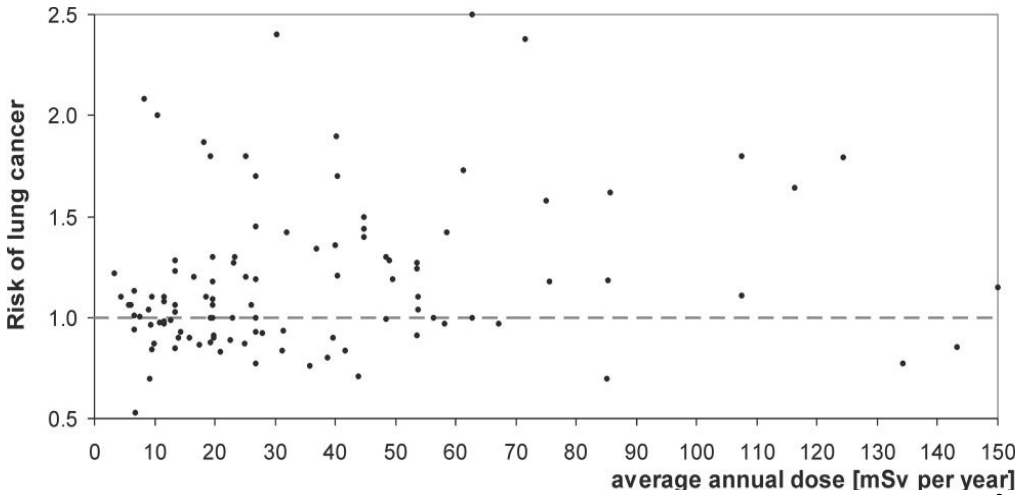

Figure 2. All published data sets for lung cancer relative risk versus radon dose rate[2]. The risk of lung cancer incidence or mortality. The original data points from 28 studies appear as-published without uncertainties to maintain the readability. Dotted line corresponds to relative risk RR=1. The reference points for the lowest doses set in original papers to RR are not presented (1 mSv per year to lungs 55.9 Bq m^{-3}).

Public concern for any nuclear or radiation risk has meant that no stone has been left unturned that might expose a source of danger. Often studies have asked loaded questions in the name of caution, and results have been accepted whose statistical significance would be dismissed in other sciences. An example is the study of lung cancer due to chronic exposure to radon, in homes and workplaces. A recent study of all 28 published sources has shown that, overall, there is no convincing evidence for a correlation when the effect of various assumptions is taken into account; Figure 2 is a

1 More extensive discussions are given in the book *Radiation and Reason: The Impact of Science on a Culture of Fear* and the article *Public Trust in Nuclear Energy* available on the website www.radiationandreason.com.

2 Fornalski and Dobrzynski, Health Physics 10; 265-273 (2011) http://journals.lww.com/health-physics/Abstract/2011/09000/Pooled_Bayesian_Analysis_of_Twenty_Eight_Studies.6.aspx

qualitative summary taken from that study.

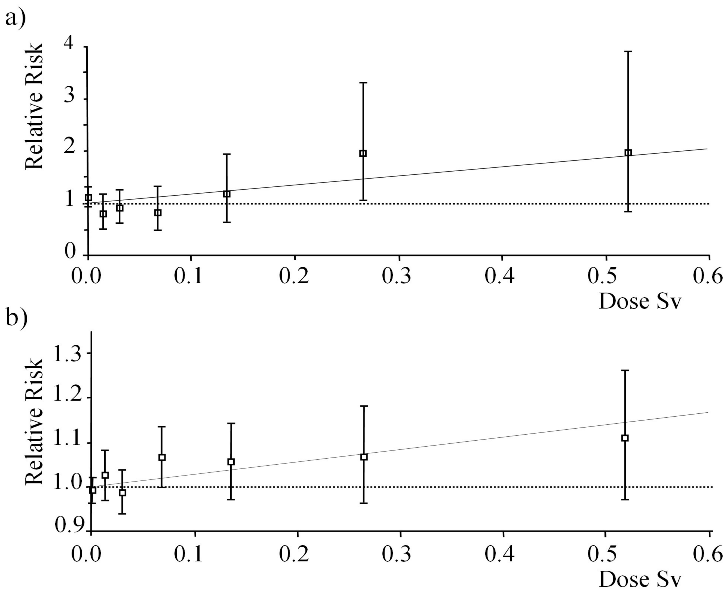

Figure 3. Dependence of relative risk of death on accumulated lifetime radiation dose for all UK radiation workers. The dotted line is at 1.0. The sloped line is the fit of Muirhead.[3] The bars are 90% CL. a) Leukaemia (excluding CLL); b) All malignant neoplasms (excluding leukaemia).

Similarly the effect of low chronic doses for large numbers of radiation workers shows no more than a statistical hint of increased risk at low doses. Figure 3 shows an example. Such studies have not answered the questions convincingly.

We confine our attention to a small number of data sources that are beyond statistical doubt and that address the four areas: cell death from an acute dose; cell death from a protracted dose; cancer from an acute dose; cancer from a protracted dose.

- Cell death from an acute dose. Figure 4 refers to the 237 initial firefighters at Chernobyl who received high doses in a short period. Within a few weeks 28 were dead from ARS. Further deaths since then were probably not related to radiation. The crosses on the figure follow a typical stabilisation curve with a threshold of 2000 to 4000 mSv. The curve shows similar data for laboratory rats.

- Cell death from a protracted dose. A century of experience with clinical radiotherapy has shown that the cells of a tumour are killed most effectively with a protracted dose in the range 40,000 to 80,000 mSv, given as a series of daily "fractions" over a period of several weeks.[4] During this time healthy peripheral tissue may receive more than 1000 mSv every day and yet recover, showing that, as a general rule, on this timescale doses do not accumulate towards cell death. The action of DNA repair mechanisms in a few hours is confirmed in vitro studies of cells in the laboratory. (While there is wide public experience of successful radiotherapy delivered in this way, there is a real prospect that in the future wider use of ion beam therapy will reduce these peripheral doses significantly.)

- Cancer from an acute dose. Data from the continuing study of the residents of Hiroshima and Nagasaki, who survived to 1950, have shown no significant evidence for radiation-induced cancers below 100mSv. The doses were due to acute gamma radiation and some neutrons from the explosion itself, unlike at Fukushima where most doses are due to

3 Muirhead CR. et al. *Mortality and cancer incidence following occupational radiation exposure*, British Journal of Cancer 2009, 100, 206–212. http://www.nature.com/bjc/journal/v100/n1/full/6604825a.html

4 Radiotherapy Dose Fractionation. Royal College of Radiologists, 2006 http://rcr.ac.uk/docs/oncology/pdf/Dose-Fractionation_Final.pdf.

radioactive decay and so protracted over a period. The data are shown in Table 1 for solid cancers and leukaemia separately.

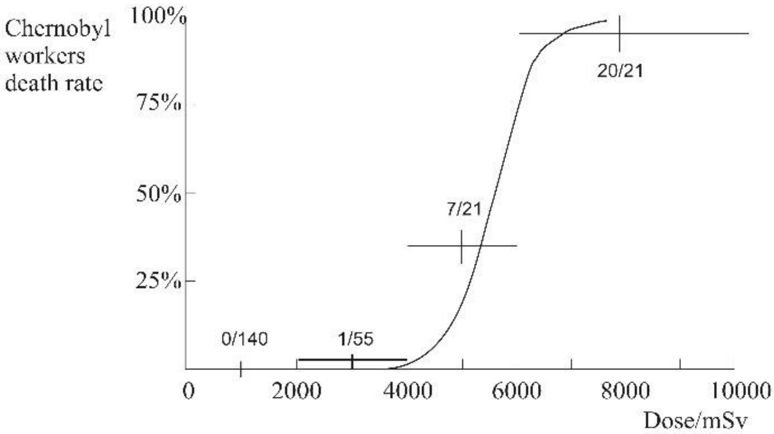

Figure 4. The mortality of Chernobyl workers from ARS, shown as number died/total for each band of acute dose. The error bars are statistical. The curve is for rats.

Dose range milli-sievert	Number in 1950	Cancer deaths (excl. leukaemia)		Leukaemia deaths	
		total rate	rate from radiation	total rate	rate from radiation
Less than 100	68467	11.2%	0.09%	0.2%	0.01%
100 to 200	5949	12.3%	0.7%	0.2%	-0.01%
200 to 1000	9806	13.2%	1.9%	0.6%	0.3%
More than 1000	1829	24.1%	8.1%	3.5%	2.4%
All	**86611**	**11.7%**	**0.6%**	**0.3%**	**0.1%**

Table 1. Cancer deaths among 86611 Hiroshima and Nagasaki survivors, 1950-2000, separated by dose bands [5](Preston et al 2004). The total radiation-related deaths from solid cancer and leukaemia were 480 and 93, respectively. The rates highlighted in green are consistent with zero, statistically.

4. Cancer from a protracted dose. Very few sets of data show unambiguous undisputed evidence. An exception is the incidence of bone cancer among painters who decorated the faces of clocks and instruments by hand with luminous radium-based paint in the period 1910-1950. Initially the painters licked the tip of their brushes and the radium migrated to their bones exposing them to steady life-long alpha radiation. The incidence of bone cancer is naturally low and its correlation with systemic activity is evident from the slide based on data from Rowland[6]. Symbols distinguish bone cancer from other causes of death. In 1926 the link was revealed and the licking of brushes ceased and no further malignancies were recorded for new entrants. Altogether the data show a cancer threshold at about 3.7 MBq,

5 Preston, Dale L. et al (2004) Radiation Research. 162: 377–389. http://www.bioone.org/doi/abs/10.1667/RR3232

6 Rowland RE *Radium in Humans: A Review of US studies* Argonne National Laboratory 1994 ANL/ER-3. http://www.osti.gov/accomplishments/documents/fullText/ACC0029.pdf with comment (2004) http://www.rerowland.com/Dial_Painters.pdf

corresponding to about 1.3 Gy per year as a whole body dose. Rowland in his paper quotes 10 Gy as a lifetime threshold. Alpha radiation causes about 20 times as much damage as gamma for the same energy dose, as prescribed by ICRP and explained by the high local concentration of energy deposited. Interpreting these figures very conservatively by discounting the factor 20 altogether, we may conclude that there is evidence for a threshold for chronic radiation to induce cancer that is safely above 1.3 Sv per year or an accumulated lifetime dose of 10 Sv. This generalisation may seem unjustified, but initial radiation damage is very non-specific and its effect indiscriminate. It is the damage to DNA that is important and that is common to all cells. The only differences are in the deposited energy concentration (already allowed for) and in the cell cycle and repair readiness of different cells according to age and function. Given the conservative factor of 20, a general safety limit of 1.3 Sv per year (and 10 Sv for a lifetime) seems both cautious and reasonable.

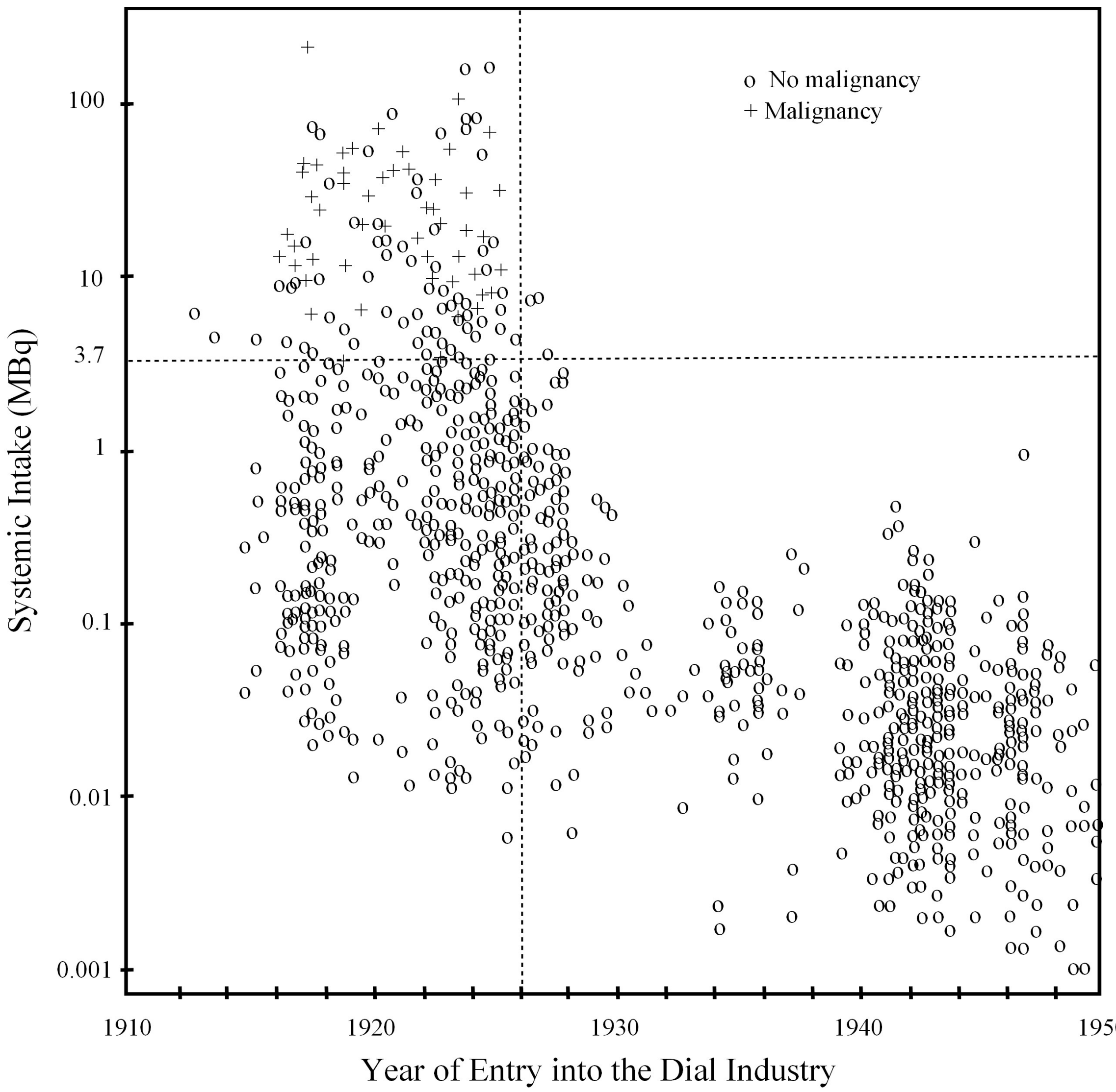

*Figure 5. Death of dial painters associated with (**+**) bone cancer and (**o**) otherwise, according to absorbed activity and year of entry. The dashed lines represent 1926 and the apparent activity threshold for bone cancer at 3.7 MBq.*

While some repair mechanisms may act within a day, many cell cycles are much longer and it seems right to take the more conservative period of a month when considering safety. Then an acute dose limit of 100 mSv and a chronic dose rate limit of 100 mSv per month are both seen to be at or below the practical thresholds of detectable risk.

Most radioactivity that is absorbed into the body, including caesium, is fairly uniformly spread and therefore does not lead to localised overloading. The one case where this is untrue is iodine. Radioactive iodine, along with any stable iodine in the body, is concentrated in the thyroid gland, particularly of young children whose diet is iodine deficient. Because the gland is small and the iodine has a short half-life, the radio-biological defences are easily overloaded. At Chernobyl some 6000 children were treated and 15 died, but at Fukushima no cases are expected as the diet is naturally rich in iodine, prophylactic tablets were often taken and the exposure to radioactive iodine was much less.

Figure 6 Monthly doses depicted as areas:
- Red, a radiotherapy dose to a tumour, fatal to all cells, 40,000 mSv per month.
- Light red, a radiotherapy dose tolerated by peripheral healthy tissue, 20,000 mSv per month.
- Green, a suggested conservative safe dose, 100 mSv per month (AHARS).
- At the point of the arrow, current ICRP "safe" dose, 0.1 mSv per month (ALARA).

How different are these thresholds of measurable risk from the safety limits usually applied? Figure 6 depicts monthly doses as areas: the red rectangle is a lethal dose to a tumour; the light red rectangle is a high dose to peripheral tissue from which members of the public usually recover and return home thankful for the treatment; the green rectangle is the safe dose rate discussed here, As High As Relatively Safe (AHARS); the area of the small dot is the public limit recommended by ICRP on the basis of the As Low As Reasonably Achievable (ALARA) philosophy (1 mSv per year). The ALARA figure is 1000 times smaller than AHARS. Why?

At the time of the Cold War fear of radiation was an important and effective international political weapon. Many people in democracies expressed their fear by marching, demonstrating and voting for a radiation-free life. That is the origin of ALARA which makes no reference to any actual risk level. However it still underlies the exceptional official attitudes to radiation and safety recommended by ICRP.[7]

So what were the consequences at Fukushima? The impact of the actual radiation and the released radioactivity for workers and public have been zero, as expected on the above criteria. In the next 50 years there is unlikely to be more than one single case of radiation-induced cancer, buried among all the other "natural" cases. There may have been superficial beta-burns, but no significant hospital cases. In the first few days when information was scarce, evacuation was appropriate while questions of re-criticality were checked out, but people could have been allowed to return home in a couple of weeks.[8]

Restrictions on contamination of food by radioactive caesium started at 500 Bq/kg (July 2011)[9]. At

7 ICRP Report 103: 2007 Recommendations. http://www.icrp.org
8 BBC World Service 26 March 2011 http://www.bbc.co.uk/news/world-12860842
9 Japanese Government *food regulations* 27 July 2011.

this level a single CT scan is equivalent to the personal consumption of 1 tonne of contaminated food. The only effect of such a restriction is the catastrophic impact on farmers, as was found in Scandinavia after Chernobyl where the restriction was relaxed to 6000 Bq/kg after six months. However, in Japan the restriction has been tightened to 100 Bq/kg (April 2012), thereby distorting public reaction yet further.

Appeasing fear is not effective and the consequences are well known. It causes, not only a collapse of confidence in the structure of society, but also a public health disaster including suicides, alcoholism, hopelessness, depression and bed-wetting. The IAEA report[10] on the health consequences at Chernobyl describes the same effect, but the authorities in Japan do not seem to have read it. The effect of closing the power stations in Japan, and in Germany too, are having, and will have, serious effects on both the world economy and the world climate through the use of substitute fossil fuels. All of this without reason or understanding.

We in the nuclear community have been in a position to understand and correct what has gone wrong. Here is a list of mistakes that we have made:

1. In our own minds, as well as the public's, we have neglected to distinguish the failure of reactors from the release of radiation that hurt hardly any one. A hydroelectric dam that fails releases enormous stored energy, often with considerable loss of life. We did not explain to the public that the nuclear story is very much better. As a result they remain frightened by the energy.
2. We have failed positively to link in the public mind the benefits of radiation in medicine, as in Figure 7, with the technology of nuclear energy. The good story should be easy to build on, but, instead, fear about nuclear has made life more difficult for clinical medicine
3. We have allowed fear of waste to mushroom out of all proportion. As illustrated in Figure 8, nuclear waste is small in mass, mostly solid, not discharged, not contagious, not permanent and generally valuable. This is an industrial problem requiring proper open management, not a threat to the world!
4. We have appeased fears of radiation with unjustifiable safety levels instead of teaching citizens, in the way that the Japanese learn about tsunamis and earthquakes. We have been tolerant of unnecessary jobs and growth in a nuclear safety industry, built on fear instead of understanding and the well being of society. We have allowed nuclear costs to become inflated for no reason that is beneficial.
5. Effective safety is a matter of understanding the world and of education. Figure 9 shows a plastic shopping bag that illustrates the point succinctly in terms of personal responsibility, enjoyment of life and survival. We have allowed people to think nuclear technology is too hard for most to understand. We have defended what we have to offer the world from behind walls of expertise. It should not be like that. We should explain the science, the beauty of the natural protection of biology that stabilises life, and the extraordinary natural non-proliferation locks on nuclear energy afforded by physics. We should explain that it is the natural radioactive decay heat of the Earth that drives tectonic plates, earthquakes and tsunami - hence the disaster. The decay heat of the reactors caused a serious problem, but as a disaster it was at least 18,880 times smaller.
6. We have watched for 60 years while nuclear-inspired political fear ran riot, wasting enormous resources and diverting attention from the real global threats to civilisation: socio-economic stability, climate change, population, food and fresh water.

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http://www.kantei.go.jp/foreign/kan/topics/201107/measures_beef.pdf

10 AEA (2006) *Chernobyl's Legacy.* International Atomic Energy Agency. http://www.iaea.org/Publications/Booklets/Chernobyl/chernobyl.pdf

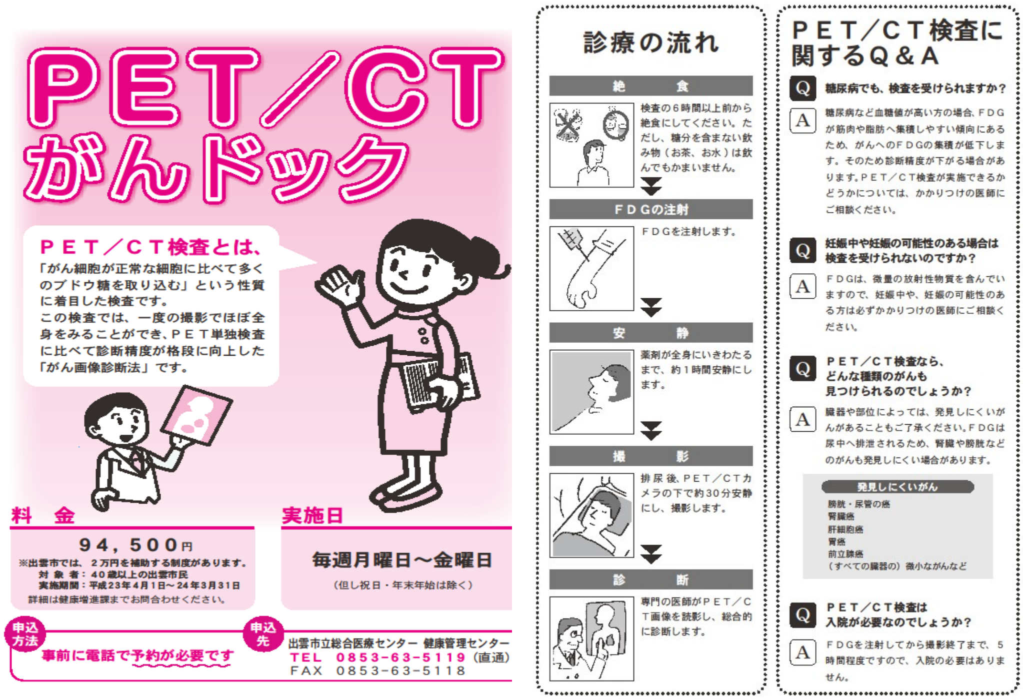

Figure 7. A poster advertising the availability and benefit of scans using internal and external sources of radiation. The (quite harmless) radiation dose (10 mSv) from a single scan exceeds the dose received by eating 5 tonnes of food described as "contaminated" (100 Bq/kg caesium-137) by the Japanese regulations introduced in April 2012.

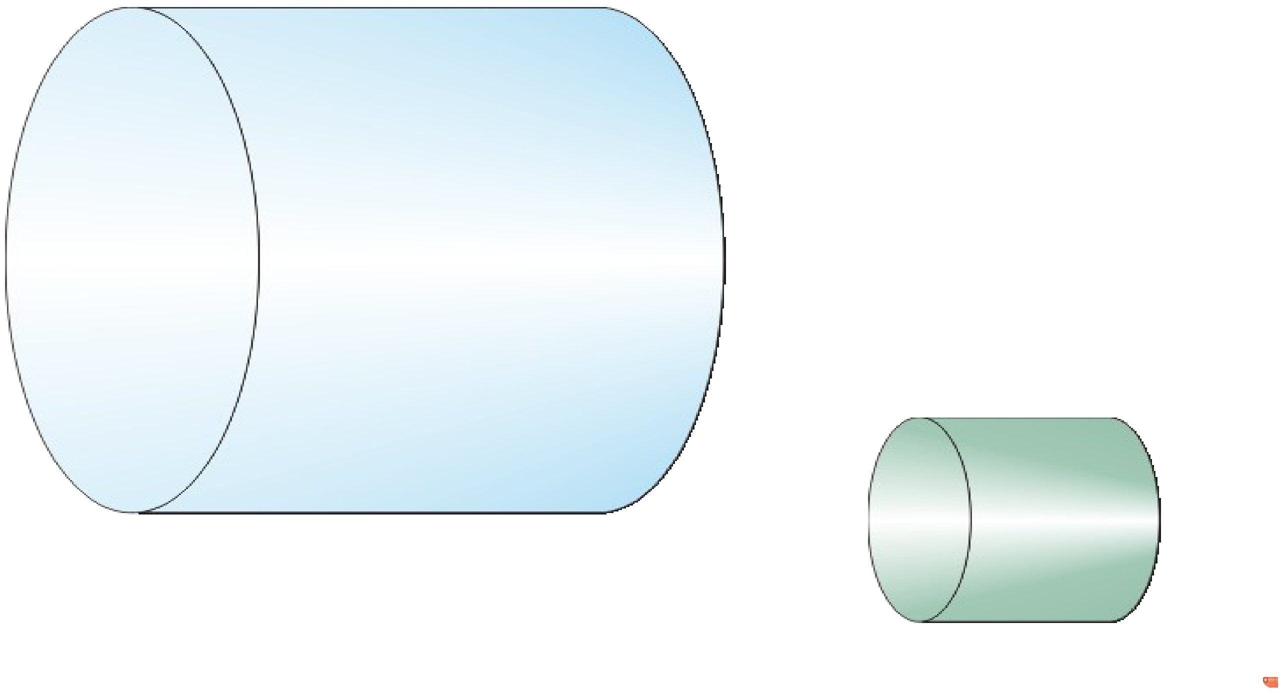

Figure 8. Canisters, each volume representing the mass of waste per person per day (UK).
On the <u>left</u> 30 kg CO2 from fossil fuels. Direct atmospheric discharge. Fire is thermal chain reaction, contagious, kills hundreds of thousands per year.
In the <u>centre</u> 2 kg of biological waste including faeces.. Direct discharge into water. Biological chain

reaction, contagious, resulting disease kills millions per year.
On the right 1/4000 kg of high level nuclear waste. Not released and largely solid, easily buried. No chain reaction (outside a working reactor), not contagious, tiny number of deaths in 50 years, valuable as fuel.

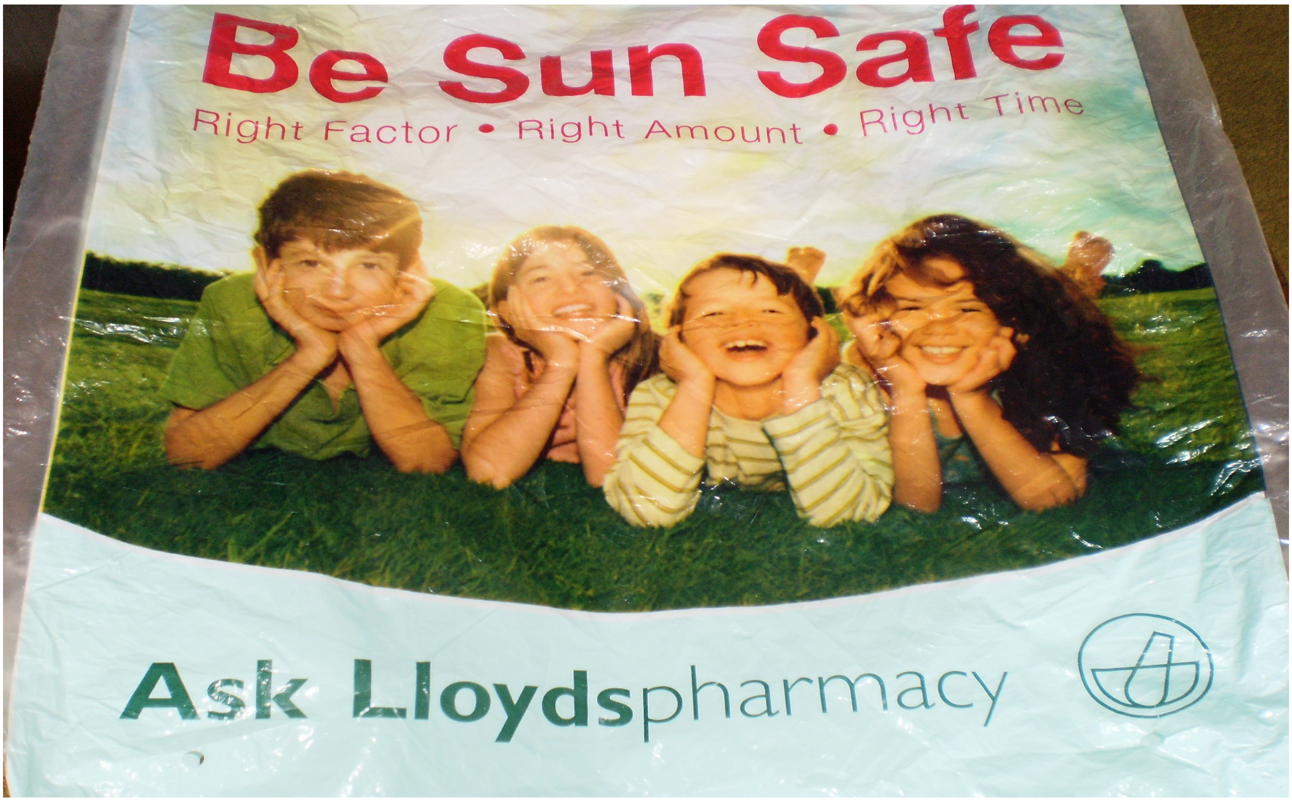

Figure 9. A plastic carrier bag giving simple accessible advice about personal responsibility for safety from ionising radiation (ultraviolet in sunshine). The advice engages with enjoyment of life and common sense, not official safety regulations.