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A worldwide group of Scientists for the Public Understanding of Radiation (SPUR)[§] issues a call based on simple commonsense arguments to dispel some of the myths and fears surrounding radiation and to suggest a sea change in international attitudes towards it.

Nuclear Radiation – friend or enemy?
Its safety and its benefits at low levels justify its wider acceptance for improved public health and economic prosperity

Summary

The health and economic prosperity of the human race depend on applications of science in engineering and medicine, and these have involved the outer (or electronic) part of atoms. Use of the inner (or nuclear) part has raised public and political apprehension when used for energy production but less so when used for human health *e.g.* following the legacy of Marie Curie. The cause of this concern is historical and cultural with no basis in science. Appreciating this misunderstanding in everyday terms is not difficult, but future prospects for world economic prosperity and a sustainable environment depend critically on overcoming these concerns through explanatory education and improved public trust in science. Only then may the known benefits of nuclear technology (access to power, clean water, food preservation, as well as advances in healthcare) be widely accepted and realised.

Effect of influences on health

There is a popular saying *"you can have too much of a good thing"*. So it is with the health effect of most agents -- the right amount may be healthy or essential but too much is harmful, whether it is a drink of water or a dose of aspirin. The principle also applies to physical exercise; some is much better than none, but an excess causes injury. If we draw a plot of health benefit against the dose of exercise taken, we would get a curve like the one shown below in Figure 1.

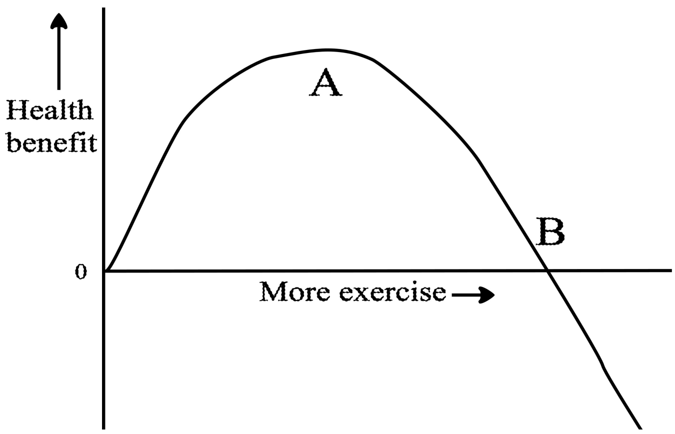

Figure 1. The positive and negative effects of exercise on health

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The most beneficial amount of exercise would correspond to point A, but any further exercise beyond point B would be detrimental. This idea was described five centuries ago by Paracelsus, the physician and botanist (1493-1541), who wrote "*Omnia sunt venena, nihil est sine veneno. Solo dosis facit venenum",* that is "*Everything is poisonous, nothing is without poison, but it's only the dose that makes it poisonous.*" A name for this behaviour is *"biphasic"* – in one range of dose the benefit is positive and in another negative.

Actually, experience suggests that this curve does not tell the whole story. In the case of a drink of water, after a few hours another drink would be beneficial. Similarly for medication, the doctor's instruction says how often to take another dose. This period might be the recovery time or the time for a dose to leave the body. Physical exercise, too, should be repeated every day, even though over a number of days the total dose of exercise might exceed what was advisable in a single day. Neglect of the time involved can make the meaning of the curve quite deceptive.

But something else can happen too; as the days go by, you start to get fit from the exercise regimen and would then benefit from more exercise each day without getting hurt or exhausted. On the curve of daily benefit, the points A and B start to migrate to the right. This is an example of the process of *adaption,* familiar enough from experience of everyday life -- no fancy maths or science is needed to understand the principles of what is happening, although *how* the body achieves this is a matter for biological study. And there is another important question: *"How long does this adaptive effect persist once you stop the exercise?"* The efficacy of exercise for general health is well known[1].

Of course we should not assume without evidence that the reaction to every influence behaves in this way. Nevertheless in biology examples are certainly widespread because evolution has stabilised the design of life to match conditions, and when conditions change a little the stability adapts accordingly. (Such stability with adaption is no stranger to the effective design of engineering and electronic systems too.) In particular, life has evolved such stability in its response to sunshine. The diagram below illustrates how the spectrum of solar radiation includes visible light, shown as a rainbow of colours, and extends to longer wavelengths, the infrared (IR) range, as well as shorter wavelengths, the ultraviolet (UV) range.

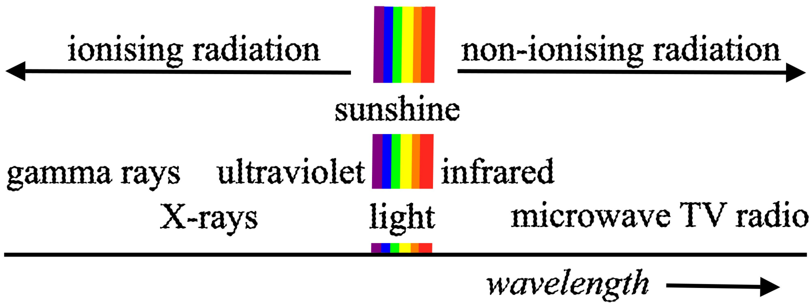

Figure 2. Regions of the radiation spectrum

The effect of IR on living tissue is mainly to heat it. This is harmless unless it raises the temperature to the point that it starts to burn which would be painful. To the right in the diagram are shown other forms of radiation such as microwaves that are *non-ionising* and considered safe at low levels. However, the effect of UV is different because it can break chemical bonds, even without heating or hurting at the time of irradiation. In fact all *ionising radiation*, shown to the left of light in the diagram (including X-rays and gamma rays), can result in molecular damage and the creation of oxidants similar to those produced in normal metabolism[2]. Life is particularly vulnerable to damage of the DNA molecules which control the cellular mechanisms of living tissue. Within a day of irradiation by UV cells may die in large numbers, apparent as sunburn which may be severe though seldom fatal. In addition, perhaps years later, skin cancer may develop originating from faulty repairs of DNA that escape the vigilance of the immune system, and this can be fatal if not treated.

In 2009 there were over 9000 such deaths in USA, based not on some calculation but on actual annual mortality figures[3]. Nevertheless some significant exposure of the skin to UV is important for the production of Vitamin D and the avoidance of Rickets. So the benefit from UV follows the general biphasic curve. Sunbathing in moderation is an accepted pleasure in life and it is notable that people do not take their vacations exclusively by starlight or deep underground, just to avoid the UV radiation and its related cancer risk. There is no plethora of international committees to discuss this significant danger[4] – just gentle public education from doctors and pharmacists pressing families to use blocking agents and to restrict their exposure periods, especially at the start of a vacation. After a few days the exposure can be extended with less risk – a matter of adaption, similar to a keep-fit programme. In summary, the public is made aware of the effect of UV without a great ballyhoo and the risks are in the same range as others encountered in life (US figures for annual deaths per million population: skin cancer 30, road traffic 110, fire 11). It may be a matter of life and death for the individual, but, in spite of a fair number of identified deaths every year, nobody would choose to threaten the economy or social health of a whole society on this account.

The effect of ionising radiation and radiation safety

Unlike UV rays, X-rays and gamma rays can penetrate the skin but they are otherwise similar; they too can cause cell death (evident as organ failure and inflammation) and cancer. There are other radiation variants, alpha and beta rays with different penetrating properties, that may ionise and damage molecules. Indeed, the effects of all forms of ionising radiation on living tissue are essentially similar -- molecular damage, directly or by oxidants, the killing of cells, the repair or mis-repair of DNA, and the removal of damaged cells by the immune system. Adaption can occur by exercising these responses to all forms of radiation and other sources of oxidative attack too[5]. Survival depends on maintaining the cell cycle in the short term and controlling malignant growth in the long term.

Like gamma rays, alpha and beta rays are emitted by unstable radioactive atoms, most of which are natural (older than the Earth). These atoms and their radiation are well known and have been studied for a century in which time they have been used for improved health. Diagnostic radiation scans use quite moderate exposures but radiotherapy treatments (RT) employ exposures some 5000 times greater to kill cancer cells, more than 50 Gy[6]. Significantly, treatment is given as a daily sequence spread over 4-6 weeks – this enables the cells of the nearby healthy tissues to recover each day from the unavoidable "friendly fire" received as the tumour itself is treated. This peripheral dose, each day about 100 times the exposure of a single diagnostic scan, carries a risk of inducing a secondary cancer several years later. Such a cancer can often be treated and the risk is a small price to pay to cure the current cancer that is presenting an imminent danger. Personal experiences of such treatment have been received by the public in almost every hospital worldwide every week in the past century. The radiation exposures are not secret and can be found posted on the internet[7]. The public is aware that the outcome of treatment is usually positive in spite of the high radiation dose. (If the cancer has already spread, or metastasised, the treatment may be palliative and the beneficial outcome limited.)

Current safety regulations for the public in the environment are designed to ensure that doses are kept As Low As Reasonably Achievable (ALARA) under limits, which are many *thousand* times lower than those used in medical treatment, and over a hundred times lower than the doses received by the public naturally in some parts of the world without any observed increased illnesses. The scientific basis of ALARA is the Linear No-Threshold (LNT) Hypothesis which is supported neither by data nor by common sense. Put simply, it would replace the biphasic curve of Figure 1 by a straight line pointing downward and describe damage as increasing steadily with dose. Contradicting the findings of modern biology the regulations assume that biological damage accumulates, uncorrected and unguarded, and that any radiation dose however small is dangerous. This philosophy, a political imperative that dates from the time of the Cold War with its threat of nuclear holocaust, is one of appeasement and public reassurance, unrelated to any scientifically demonstrable risk. National regulations are based on recommendations from international committees[8] with additional deliberations by others[9].

The detrimental effect of these regulations is made clear with some examples, mostly taken from the Chernobyl and Fukushima accidents[10].

- In spite of the fact that nobody has died from the radiation released at Fukushima – indeed there have been no significant radiation-induced casualties -- the accident was classified at the maximum severity 7 by the Japanese Government. That there would be no casualties was predicted within two weeks[11], yet it took WHO nearly two years to confirm this, still hedged with caution[12], while serious social and economic damage continued in Japan and elsewhere.
- The number of additional deaths at Fukushima due to fear of radiation is confirmed to be in excess of 1000 as a result of the forced evacuation of the elderly alone[13,14,15]. These deaths were inflicted to avoid potential radiation exposures less than 1% of those that are known to cause cancer. There have been suicides, alcoholism, family break-up and child bed wetting, too -- all symptoms of extreme social stress.
- 20 years after Chernobyl it was belatedly reported that there the dominant health effect was psychological, caused by forced evacuation and labelling inhabitants as "victims" suffering the unseen "curse" of radiation. The salutary lesson, although described in international reports[16], was ignored at Fukushima.
- On 4 April 2011 TEPCO, the utility company at Fukushima, discharged 11,500 tons of radioactive water into the ocean. It announced that this water contained 100 times the regulatory "safe" concentration of radioactivity (100 Bq per litre) and also that the water was perfectly safe[17]. This announcement destroyed public trust although both statements were true, the regulation being quite inappropriate. A simple calculation shows that drinking one litre of such water each day for three months would give the same dose as two CT scans.
- In July 2011 *radioactive contamination of food* was defined in a Japanese Government regulation[18] with the effect that the consumption of 1 tonne of such food in 3 months would be equivalent to one CT scan in that time, showing that the regulation was absurdly restrictive. Later, following popular protest, the regulation was *tightened* by a further factor of 5. A similar regulation in Norway after Chernobyl was *relaxed* after a few months[19] by a factor of 10.
- After Chernobyl, in Greece alone, there were nearly 2000 extra abortions that were attributed to fear of radiation[20].
- Currently, in March 2013, all but two nuclear power plants in Japan are shut down and the energy replaced by imported fossil fuel with serious consequences for the Japanese economy and for the environment -- all for no benefit that can be scientifically demonstrated. Germany, Italy and Switzerland, among other nations, have resolved to follow similar courses of action on various time scales. The effect on the world economy and the climate are likely to be judged severe and reckless by future generations.
- In Japan in 2011, contamination by Caesium-137 at an activity level of a few hundred Bq per litre has caused public anxiety. In 1987 in Goiania, Brazil, a redundant 50 TBq (50 million million Bq) Cs-137 source was found on waste ground by children who, attracted by its blue light, played with it for two weeks. Within a few weeks there were four deaths from radiation and 28 cases that needed surgery for radiation burns. 250 people were contaminated and there was one case of cancer in later years, subsequently treated. No further casualties have been reported by the IAEA. The maximum dose received in Japan from Cs-137 by the public has been about 1000 times smaller.

The choice between fear and study, when faced with danger

When man first used fire he found it dangerous; the flames caught and destruction spread easily. Animals ran away but he used his brain to study and learn in spite of his fear. There must have been some noisy debates at the time between anti-fire demonstrators and those who had experimented and studied it. The anti-fire party had many powerful arguments, tales of death and destruction, but they lost the vote and returned home to uncooked food and a life of cold and damp. This was an important outcome – in spite of its dangers, without fire human civilisation would not have prospered. The present clash of views over nuclear technology differs in one remarkable respect: there is no danger, at least none compared to the dangers of fire or road traffic. Reactors may have been destroyed at Fukushima but there has been no significant detrimental health effect from radiation. Even at Chernobyl where the reactor was utterly destroyed there were less than 50 deaths directly caused by radiation. Radiation deaths from skin cancer are real, identifiable and numerous, but ignored by activists; radiation deaths from nuclear accidents are zero or few, except theoretical phantoms based on the discredited LNT hypothesis. So while the fire "antis" had strong safety arguments long ago, the nuclear "antis" today do not.

What about radioactive waste and terrorist nuclear threats? These are only dangerous to the extent that radiation is dangerous. If the dangers of radiation have been overestimated, then waste is less of a problem, and terrorism too. Up to now the public have viewed nuclear waste and the threat of terrorism as unbounded horrors. This is not justified by science; it is mistaken. The problem is public fear and panic. Nuclear waste, though nasty stuff, does not spread or infect like fire or the disease encouraged by biological waste. Because nuclear energy is so concentrated, little fuel is used and little waste is created – about a millionth as much as for fossil fuel. The waste needs to be cooled, reprocessed (to retain the valuable unused fuel) and then buried after a few years -- not a bigger task than handling many chemical waste products whose toxicity persists indefinitely. The effort and expenditure lavished on nuclear waste and plant decommissioning should be reduced; the cost saving should be substantial even though vested interests would argue against that.

So what should be our attitude to nuclear technology? If we were to follow the urgings of the nuclear "antis", our prospects on planet Earth would be no better than animals, a massive reduction in numbers with a low standard of living. We should do better and follow the advice of Marie Curie who wrote *"Nothing in life is to be feared. It is to be understood."* We should study and apply knowledge as our stone age forbears did with fire. Though they were faced with a finely balanced dilemma, they did a better job at decision-making than we seem to have done recently. Generally, those in authority have insufficient understanding of science, although new prosperity depends on scientific innovation, as it has in the past. The country that first sets aside the legacy of the LNT model and embraces cheap nuclear technology with sensible safeguards will reap great rewards, and we should join such an initiative. As well as electric power, this technology can provide unlimited fresh water by desalination and cheap food preservation, harmlessly, by irradiation without refrigeration. The world needs these opportunities to expand economically, but the philosophy of ALARA and LNT stands in the way. The great 18^{th} Century economist, Adam Smith, said *"Science is the great antidote to the poison of enthusiasm and superstition"*. Fear of nuclear is such a superstition and is now ripe for exorcism.

But there is a further step to be made. Since the damage and cellular reaction found for physical exercise are similar to those for sunshine and nuclear radiation[2], it is to be expected that low levels of radiation should enhance general immunity by adaption, as has already been observed[21]. More research is needed to build on existing experience in this area and to make such clinical treatment widely available. Naturally, patient confidence in low level radiation as a benign agent is essential.

Conclusions for a more sustainable future

Mankind should engage his intelligence to maximise his chances of survival in a world of competing risks, as he did in earlier times. This should involve investing effort in the following:

- Educating the public (and media) to explain how nuclear radiation benefits everybody through medicine, carbon-free power, desalination and food preservation. To build trust this education would best come, not from government or industry, but through medical, university and school teachers without suggestion of any vested interest.
- Building further nuclear power plants of existing designs without delay to reduce fossil fuel emissions for the sake of the environment, including an end to the large-scale combustion of gas and biomass.
- International recommendations on radiation safety should be changed to encourage balance with other more conventional risks to society and the individual[22]; national regulations should accept that, sometimes, the best course of action involves choosing the higher radiation exposure, like the decision to accept rather than refuse radiotherapy treatment. Thus, following an accident and before decisions are made, the potential loss of life due to mass evacuation and the environmental consequences of closing power stations with the burning of replacement fossil fuel should be compared with any life-threatening risk from radiation[23]. Similar considerations should apply as for regular industrial safety, but currently they do not[22]. If no radiation risk can be substantiated in radiobiology, then dose thresholds should be defined, their significance explained to the public and proper allowance made for them in law. Substantiation should not be based on simple extrapolation with ALARA/LNT or motivated by a political desire to appease public fear. Today it is known that there is no substantial risk for an acute dose less than 100 mSv[10]. For the case of chronic or protracted radiation dose rates, residents of high natural background areas and radiation workers have shown no increased risk of cancer[24,25]. Only health data for which the dose rates are much higher show substantial risks, namely for the peripheral tissues of RT patients and for the "radium dial painters"[26]. These data are consistent with a dose-rate threshold somewhere in the region of 100 mSv per month[10]. International recommendations should reduce social stress, exaggerated concerns over waste/decommissioning and excessive utility charges that arise from expensive regulations that do not improve safety.
- Pursuing further clinical research into the benefits of low-dose chronic ionising radiation (LDR) for cancer therapy by the exploitation of adaption (hormesis)[5].
- Designing the next generation of nuclear fission plants and also research and development of thermonuclear power.

[1] Warburton et al http://www.canadianmedicaljournal.ca/content/174/6/801.full

[2] Fogarty et al.*Environmental and molecular mutagenesis* **52**, 35 (2011).

[3] Center for Disease Control and Prevention, http://www.cdc.gov/cancer/skin/statistics/

[4] There are regulations for artificial UV "sun" beds although these are poorly enforced http://journals.lww.com/health-physics/Abstract/2013/04000/UV_Emissions_from_Artificial_Tanning_Devices_and.5.aspx

[5] Feinendegen, Pollycove and Neumann in *Therapeutic Nuclear Medicine*. Springer (2013) http://dl.dropbox.com/u/119239051/Feinendegen-2012_Hormesis-by-LDR_Therapeutic-Nucl-Med.pdf

[6] Although radiotherapy doses are usually quoted in mGy, these are the same as mSv for most practical purposes.

[7] http://rcr.ac.uk/docs/oncology/pdf/Dose-Fractionation_Final.pdf

[8] 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

[9] Other committees IAEA, WHO, BEIR, NEA, NCRP, etc.

[10] Further discussion http://www.radiationandreason.com

[11] http://www.bbc.co.uk/news/world-12860842

[12] http://www.who.int/mediacentre/news/releases/2013/fukushima_report_20130228/en/index.html

[13] http://nextbigfuture.com/2012/08/fear-of-radiation-has-killed-761-and.html

[14] Ichiseki, H. Lancet 381, 204, (2013)

[15] Yasumura, S.et al. Public Health 127, 186-188, (2013).

[16] UN Chernobyl Forum, WHO http://whqlibdoc.who.int/publications/2006/9241594179_eng.pdf

[17] http://www.tepco.co.jp/en/press/corp-com/release/11040508-e.html

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

[19] Harbitz at al. http://www.crid.or.cr/digitalizacion/pdf/eng/doc10879/doc10879-contenido.pdf

[20] http://www.bmj.com/content/295/6606/1100.extract
http://library.temple.edu.libproxy.temple.edu/ - qt-homepage_search_tabs-ui-tabs2

[21] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2477702/

[22] Fresh evidence of the failure of radiation safety policy www.radiationandreason.com/uploads//enc_ChaplinSubmission.pdf

[23] At Fukushima, after the first week or two, it would have been better for the evacuees to have returned home.

[24] http://www.sciencedirect.com/science/article/pii/S0273117707001032

[25] hhttp://www.bmj.com/content/331/7508/77 with correction to Canadian data: http://nuclearsafety.gc.ca/pubs_catalogue/uploads/INFO-0811-Verifying-Canadian-Nuclear-Energy-Worker-Radiation-Risk-A-Reanalysis-of-Cancer-Mortality-in-Canadian-Nuclear-Energy-Workers-1957-1994_e.pdf

[26] Rowland RE http://www.osti.gov/accomplishments/documents/fullText/ACC0029.pdf with comment (2004) http://www.rerowland.com/Dial_Painters.pdf