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Everyday risks

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This paper, presented at the 1991 Pan-American Science conference in Venezuela, was one of the keynote addresses and was warmly received by the delegates.

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The first part of the paper, entitled 'Everyday risks', appears in this issue of *Physics Education* and will be followed by the second part ('Risks of radioactivity') in the March issue and the final part ('Public risks due to nuclear industry') in the May issue.

John H Avison, Honorary Editor

'When you cross a road, look to the right at first, then look to the left at the middle of the road'—we used to tell our children and pupils, but we don't add:—'look up as well, to see whether a chimney is tumbling down or whether an aeroplane is falling on your head'. The latter events still have a finite probability! If two people die of these accidents in one year in the United States, the probability that a citizen will die is 1/100 000 000 years, i.e. 10^{-8}/year. By everyday experience, common sense judges such a risk negligible (practically zero).

The mathematical definition of risk is $R=PC$, where P is the probability of occurrence and C is the seriousness of the consequence. (In the case of certainty, $P=1$. In the case of death, $C=1$). According to the definition of probability, if N people are exposed to the same risk R, the *collective risk* (i.e. the expected number of lethal casualties due to this exposure) is NR. For a simple discussion, let us introduce the concept of *microrisk* as 1/million (10^{-6}), i.e. as a risk that may kill one from among one million people exposed. According to international assessment, one microrisk is incurred when

travelling 2500 km by train,
flying 2000 km by plane,
travelling 80 km by bus,
driving a car for 65 km,
bicycling for 12 km,
riding a motorcycle for 3 km,
smoking 1.5 cigarettes,
living two months with a smoker,
drinking half a litre of wine,
living in a brick house for ten days,
breathing in a polluted city like Budapest for three days.

Looking at these numbers, one may conclude that people consider a few microrisks affordable: 1 microrisk is about smoking a cigarette, or driving your car to the next town or riding a motorcycle to pick up a friend. As a matter of fact, in legal terms the Congress of the USA considers *one microrisk to be negligible*.

The 'right of knowledge' act (accepted by the State of California with a majority of two-thirds in 1987) states that 'nobody may be exposed—consciously or unconsciously—to a chemical effect that may cause cancer or genetic harm, without calling the attention of the person to be exposed to this danger.' But in court one must know: what does a punishable *non-zero risk* mean? A physicist may be inclined to say: 'What I can measure'. According to the legal praxis in California, an exposure above 10 microrisks must not be caused without advanced warning. This is why health warnings must be printed on every packet of cigarettes.

One microrisk may look small in itself. But let us consider a state of $N=10$ million inhabitants (like Hungary). If each person is exposed to the 'affordable' 1 microrisk, this means a collective risk $NR=10$. Ten innocent casualties does not

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look such a low price any longer! This example shows that the *presentation of risk* offers a chance to manipulate the public. For example, after the Three Mile Island nuclear accident a local newspaper wrote: 'The emission of active noble gases increased the risk of a person living in that environment by the equivalent of smoking half a cigarette.' (It is reassuring, isn't it?) The three million people living in the affected environment were informed by another local newspaper that: 'The irresponsibility of technocrats kills two innocent victims!' (It is terrible, isn't it?) Simple multiplication shows that the two statements are equivalent! Anyone who quotes numerical data to the public or to students has to do it with the utmost responsibility. Society can be educated for responsible democratic decision-making (e.g. about the route of progress) by being schooled in rational thinking and by obtaining relevant information.

Chemical risks

Alvin Weinberg recalled recently that emotional anxiety may be felt in society about the dangers of modern science and technology. This is why he has named the (otherwise peaceful) 1980s 'the age of anxiety'. One component of anxiety is a lack of scientific/technical knowledge about low-level risks. (Even more ignorance may be experienced by citizens, journalists, and in some countries even by the decision-makers.)

Yes, it is a hard fact of life that each of us has to die—sooner or later. (By being born each of us takes a risk $R=1$ to die.) But in the 20th century life expectancy has increased from 35 years to 70 years in Hungary! It is true that the number of victims of tuberculosis went down from 18 000 to 1000 per year in the same period, but deaths from lung cancer rose from 350 to 6400 per year. In Hungary, air pollution is estimated to be the cause of 6% deaths, which means 10 000 casualties per year, comparable to the number of victims of smoking).

As the saccharin controversy—among others—indicates, it is rather difficult to make a quantitative assessment in the case of chemical risks. For simplicity, the Environmental Protection Agency (USA) has adopted a simple proportionality between dose and risk (with no threshold). For example the slope of this straight line is 100 microrisk/g of arsenic. In Hungary, the maximum allowed arsenic content of drinking water from country wells is 0.05 mg/litre. This means that drinking half a litre of water per day from such a well gives you a microrisk of cancer in a year. (There are some country wells with an arsenic concentration over ten times higher. In the last decade, drinking their water has been forbidden because the risk of drinking it exceeds 10 microrisks/year.)

Let the Sun shine?

'If you don't go out in the sunshine, you may get rachitis (rickets)'—we were told by grandpa. It is true: the near infrared radiation contributes to our production of vitamin D.

The first humans emerged in Africa; they were evidently dark-skinned. When some of them were driven by overpopulation to cloudy Europe, a mutation decreasing the pigment production was an advantage: the skin collected more sunshine, so the body could produce more vitamin D. This is why doctors recommend a sun-lamp for the long dark winter afternoons in Northern Europe.

The hard ultraviolet photons of sunshine break up the molecules of air, which is how the ionosphere has been produced. Deeper atmospheric layers are reached only by soft ultraviolet photons (0.5–0.7 aJ) and by visible photons (0.25–0.5 aJ). In the first billion years after the creation of the Earth the bombardment of soft ultraviolet photons made the survival of complex organic molecules impossible; life could not evolve on land. The green plankton in the sea, however, began to pump oxygen into the atmosphere by photosynthesis ($h\nu + CO_2 \rightarrow C + O_2$), and the ultraviolet photons broke up the oxygen molecules, producing ozone ($h\nu + O_2 \rightarrow O + O$, $O_2 + O \rightarrow O_3$). The valence angle of ozone (O_3) is about 120°, it contains delocalized electrons on a pathway 0.25 nm long. These absorb the near ultraviolet photons ($h\nu = 0.6$ aJ). Under the protection of this ozone shield life dared to occupy the continents.

In the 1980s British scientists noted that at springtime the thickness of the ozone shield dropped to one-sixth of its usual value above Antarctica. The ozone hole reached a record size in 1990. The suspects were found on the spot: they were Freon-type molecules (CFCs), used in sprays, in refrigerators and in air conditioners. These man-made molecules are durable enough to diffuse up to the stratosphere, where they catalyse the decay of ozone. Ultraviolet photons cross the broken ozone shield, they harm leaves and may cause skin cancer in human beings.

The populations of the USA and Australia are especially sensitive (think of President Reagan's nose): they are pale skinned people who like to get a sun-tan. Skin cancer is three times more common in sunny Texas than in rainy Iowa. Most skin cancers occur in Australia. The number of skin cancer cases has doubled in 20 years and quadrupled in 40 years even in Europe.

According to the Environmental Protection Agency (USA) 1% thinning of the ozone layer may increase the ultraviolet radiation by 2%. This could cause 6000 extra megamelanoma cases in the USA and several tens of thousands worldwide. The most recent measurements indicate that the decay of the ozone layer has already exceeded this value. This is why a sun-tan is already out of fashion in California and on the Riviera. This is why the Montreal Protocol urges a suppression in the use of Freon-type compounds.

Ultraviolet radiation is harmful because it excites and destroys organic molecules.

We shall focus our attention on ionizing radiation, not only because radioactivity is the most feared, but because it can be measured, checked, researched and controlled the most easily.

Radioactivity

The unit of *activity* of a sample is 1 Bq (becquerel) = 1 decay/second. (If a sample contains N radioactive nuclei of half-life T, then its activity can be calculated as $A = 0.7N/T$.)

Radioactive decay liberates energy: it produces ionizing radiation. This radiation may destroy molecules in the human body, disturbing the delicate network of the biochemical metabolism. The overall number of ions may be considered to be a measure of the effect of this radiation. The dose is the ratio of the absorbed ionization energy E to body mass M, that is E/M.

(The corresponding unit is 1 Gy = 1 gray = 1 joule/kg = 1 J/kg. The differences in the biological effects of different particles can be taken into account by a quality factor Q. The electrons and x-ray quanta produce ions with a lower probability than α-particles (see figure 1), so they have a smaller chance to overload a single cell with ions; the defence system of the cell can cope with them more easily: $Q = 1$. The harm may be greater for heavier particles ($Q > 1$). The *dose equivalent* is defined as $D = QE/M$. Heavier charged particles are absorbed easily; therefore the public are exposed mostly to x-rays, gamma-rays and electrons. For the understanding of *everyday risks* this distinction is not so relevant.)

The unit of dose equivalent D is 1 Sv (sievert) = 1 J/kg (for x-ray, beta and gamma radiation). We know from the bitter experiences of Hiroshima and Nagasaki that $D > 10$ Sv is lethal. $D = 4$ Sv results in death with a probability of 50%. A dose of a few Sv causes acute symptoms (loss of hair, bleeding in the gut) within days. In everyday life much smaller doses occur, and therefore we shall use 1000 times smaller units: 1 mSv (millisievert) = 1 Sv/1000.

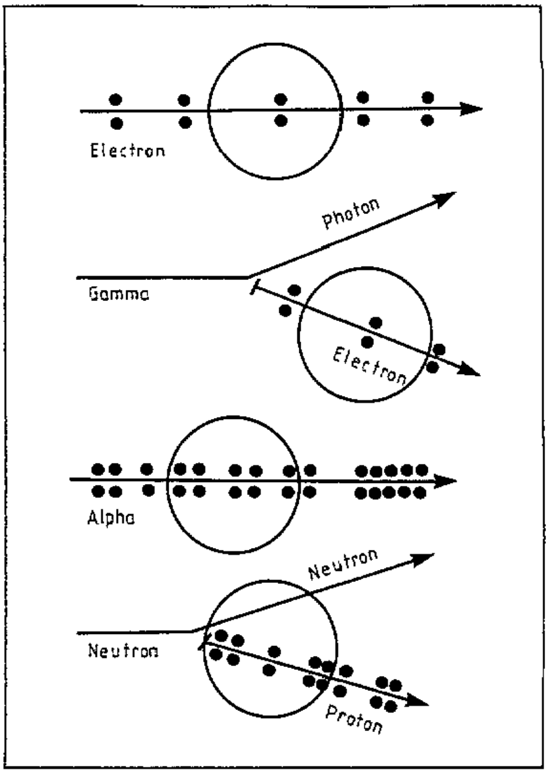

Figure 1. Alpha particles create more ions in a single cell than other particles.

There was a zone in Hiroshima and Nagasaki (a belt at a distance of 1.5–2.5 km around the epicentre) where people survived but received radiation doses of about 100 mSv. (Experts have reconstructed the dose for each of these people: where were they? indoors or outdoors? what was the roof constructed of? etc.) Their medical history and the causes of death were tracked carefully. The statistics obtained have been compared with those of the Japanese population living elsewhere. The estimation obtained by subtracting the normal mortality and by extrapolation, *assuming a linear proportionality between risk and dose*, has shown that a dose equivalent of 1 mSv increases the risk of lethal leukaemia and cancer by about 50 microrisks. (A similar medical follow-up is going on in Chernobyl.) The International Commission on Radiological Protection recommends this risk/dose factor in official calculations. (At much higher doses the factor is taken to be twice as large, but such high doses do not affect the public.) So what is the risk of 1 mSv dose equivalent?—*50 lethal cancer cases per million people exposed.* Equally risky are

to smoke four packets of cigarettes,
to bicycle for 600 km,

to drive for 3250 km,
to cross a busy road twice a day for a year,
to be x-rayed for kidney metabolism.

Are you prepared to take such a risk? (The expected answer is: 'it depends, for what?')

(The energy of a gamma-photon of natural radioactivity or a medical x-ray may be about $0.1\ \text{MeV} = 1.6 \times 10^{-12}$ J. $1\ \text{mSv} = 10^{-3}$ J/kg results in 50 microrisks. But the impact of a single photon—at a critical site—may cause cancer! This means that the attack of a single gamma-photon on a body of 75 kg creates cancer with a probability $50 \times 10^{-6} \times 1.6 \times 10^{-12}/75 = 10^{-15}$—an inconceivably small number! But one must not forget the definition of risk: a roulette ball is rolling, there are 10^{15} numbers written on the dish, but at stake is *life or death*. A single photon may cause a lethal disease, like a single arsenic atom, a single benzene molecule or a single AIDS virus. Therefore international regulation requires that the radioactivity suffered by people has to be *as low as reasonably achievable*: the ALARA principle. Translated, e.g., to the praxis of x-ray lung screening, it requires that the number of curable cases of lung cancer detected must be larger than the number of leukaemia cases caused by the x-raying.)

The law says that the artificial radiation burden on the population must not exceed 5 mSv/year (corresponding essentially to 5 microrisks/week). Medical interventions to save life may and do surpass this value. For those who work professionally with radiation the dose limit is 50 mSv/year. (the largest exposure within the Hungarian Nuclear Power Station was 33 mSv in a year.)

As we understand cancer, it begins when a cell becomes antisocial. The cell starts to multiply, spreading and wandering to any part of the body. Mice and rats have ten thousand times fewer cells and their lifetime is a hundred times shorter. It follows that theoretically their abundance of cancer should be a hundred thousand times lower than in human beings. But experience shows that they get cancer as frequently as people! By growing large, we have learned to protect ourselves against chemical and ionizing attacks pretty well.

Why can radiation be harmful?

We are made mostly of water. The most probable process of ion formation is

$$\text{photon} + H_2O \rightarrow H^+ + OH^- \qquad \text{(ion!)}$$

$$OH + OH \rightarrow H_2O_2 \qquad \text{(oxidant!)}$$

The charged ions and hydrogen peroxide molecules both disturb the biochemical network, finely tuned by enzymes within the reducing environment of a cell. A similar harmful attack happened when the photosynthesis of plants enhanced the oxygen in the atmosphere. The land animals developed an efficient defence against the attack of active oxygen (peroxide): catalase and superoxide–dismutase enzymes. This means that oxygen-breathing and ionizing radiation attack the cell metabolism in a similar way. The cells may delay these harmful consequences, but there is no complete defence. If 1 mSv/year dose equivalent means 50 microrisks/year, a person at the age of 60 years has collected a cancer risk of 0.3% due to this radiation dose. But 20% of people will die anyway of cancer! Therefore James Lovelock (the initiator of the Gaia hypothesis) argues that *breathing air is equivalent to a radiation dose of 66 mSv per year*. Should we stop breathing? (Silly question.)

The chemical affinity of atmospheric oxygen has made intense biological activity possible: it has created animals, human beings, cultures. Our bodies have developed a rather reliable defence against its dangers. That is why we can live so long. This defence works against ionizing radiation as well. A gamma-photon will harm us with the very low probability $R = 10^{-15}$.

On the basis of these numbers we shall discuss the risks of radioactivity affecting the population in the March issue of the journal.