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Report

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The risks of radiation

By Jan Willem Nienhuys

Further research into a little-known theory on the effects of low-level toxic exposure could revolutionise the way we assess radiation risk, with huge implications for the nuclear power industry, argues Jan Willem Nienhuys.

Tokyo, days after the Fukushima disaster: a radiation detector marks 0.6 microsieverts (photo: Kyodo News/AP)

Too much of anything can be harmful. If you were to drink twenty litres of water at once, it would kill you. Carbon monoxide is poisonous above a certain level, but in the brain it performs a useful function as a signal transmitter. Many drugs work fine in the right dose, but are lethally poisonous in larger amounts.

In pharmacology it used to be generally accepted that no substance has observable effects below a certain dose and that effects proportional to the size of the administered dose would only occur above a particular threshold. Towards the end of the nineteenth century the German pharmacologist Hugo Schulz (1853–1932) discovered that a particular disinfectant stimulated the growth of yeast if administered in small amounts, but destroyed the yeast cells when administered in larger quantities. This came to be known as the principle of hormesis. Hormesis is the idea that biological organisms generally react favourably to low exposures to toxins and other stressors. In other words, a limited dose of a pollutant or toxin that exhibits hormesis has the opposite effect of a large dose.

Schulz' theory of hormesis was largely ignored, however, because of his belief in homeopathy. He and his colleague Rudolf Arndt (1835-1900) presented their discovery as a universal phenomenon and as the explanation of homeopathy. But the theory of homeopathy, developed in the late eighteenth century by the German physician Samuel Hahnemann, applies to extreme dilutions of substances rather than small measurable amounts. Such dilutions are supposedly beneficial when administered to the sick. This pseudoscience is quite irrelevant to hormesis, but Schulz's linking of the two resulted in most scientists and physicians discounting his discovery.

This is unfortunate because there is a wealth of evidence for hormesis. The best recent source is a 2009 publication, *Hormesis: A Revolution in Biology, Toxicology and Medicine* (Springer, 2009), which comprises a series of articles edited by Mark P. Mattson and Edward J. Calabrese. This book gives a thorough and fascinating picture of how hormesis works. As we shall see, this is crucial to understanding the effects of radiation – and therefore to the future of nuclear energy.

Smokers and drinkers

When an organism is exposed to harmful influences, various compensatory mechanisms come into play, not only to counter the influences at that particular juncture, but also to prepare for possible repeats in the future. The immune system is just one such mechanism. Patients about to be given an anaesthetic, for example, will be asked by the anaesthetist about drinking and smoking habits. This is important because the livers of smokers and drinkers have adapted and break down the anaesthetic more efficiently, necessitating a higher dose.

On the cellular level, exposure to low concentrations of arsenic will induce the production of so-called *heat shock proteins* (HSP). These are special proteins that can chaperone other proteins and protect them from damage. They are also produced when the cells are exposed to heat. Lab experiments show that a repeat exposure to arsenic results in accelerated availability of heat shock proteins, or in greater amounts. This is the basis for arsenic tolerance, well known to ancient rulers who used this to arm themselves against would-be poisoners.

There are many biochemical mechanisms that protect humans against harmful influences. Messenger molecules both inside and outside the cell and transcription factors are involved. Through a series of intermediary steps they trigger genes that produce various kinds of protection. This extra protection is why small amounts of toxins – namely the hundreds or thousands of compounds contained in the fruits and vegetables we eat – have a net positive effect. They protect us against disease, more or less in the way that tiny doses of aspirin have salutary effects. Mattson and Calabrese's book argues that the hormetic pattern actually constitutes the basic pattern of any drug action. In the hormetic low dosage range, various health indicators, such as the risk of incurring a serious disease, improve by 30 to 60 percent compared to zero doses. And this doesn't just hold true for people; some bacteria also thrive on low doses of antibiotics.

The British authorities were so afraid of the risks posed by cars that they stipulated in 1865 that a man with a red flag should walk in front of these so-called road locomotives

Oxygen gives us another interesting example of how hormesis works. About three billion years ago, life on earth discovered the photosynthesis trick. Cyanobacteria gradually pumped oxygen into the oceans and the atmosphere. After an estimated one billion years, all the soluble iron in the oceans had been oxidized and precipitated. (That's now our iron ore.) But eventually other life forms and even the cyanobacteria themselves had to adapt to this poisonous waste material. Life succeeded so well that nowadays we can't do without oxygen.

But at the same time, as Charles L. Sanders explains in *Radiation Hormesis and the Linear-No-Threshold*

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Assumption (Springer, 2010), our cells are constantly battling against oxygen damage. It's estimated that the DNA in each of our cells is damaged twice *per second*. Compared to this, the damage caused by radioactive radiation is small. Most of this damage results from the creation of highly reactive broken molecules, so-called 'free radicals'. Depending on the method of calculation used, the wear and tear caused by oxygen is a hundred to a million times greater than the damage resulting from ordinary background radiation. Almost all of this damage is repaired, and a large repair crew of enzymes is constantly at work.

Effectively what this means is that those involved in physical work and hence using more oxygen will have more free radicals and more oxidative stress, at least in the muscle cells. But it also means that the body increases its defences against these attacks. The net effect is probably positive. In other words, physical exercise is good for you. The effect of a little abstinence is probably also positive. Those who take the car to work and spend their spare time on the couch with a bowl of crisps do not benefit from the advantages of physical exercise and reduced caloric intake.

Divide by twenty

So what about the risk of cancer from exposure to radioactivity? This is a subject Sanders' book deals with in great detail, focusing – as its title indicates – on the Linear-No-Threshold-hypothesis (LNT). This is the generally used method to estimate radiation damage, and more particularly the risk of radioactively induced cancer. As Sanders shows, the LNT-hypothesis ignores the principle of hormesis – with important implications for the way in which we perceive radiation risk.

Before discussing this in greater detail I'd like to say something about the units that are used to measure radiation doses caused by ionising radiation. Basically, the dose is measured in absorbed energy per mass of living tissue. Hence in the International System (SI), the ionizing radiation dose is measured in joules per kilogram. (In the land of the inches, gallons and avoirdupois pounds the unit is taken to be 100 times smaller.) There are two names for that unit, namely gray and sievert, abbreviated as Gy and Sv respectively. In the case of the sievert, some kinds of radiation are allocated a greater weight, but beta and gamma rays both have weight 1. If only a part of the body is irradiated, the different parts each have their own weight, but naturally the weight of all parts together is just 1.

Cancer is largely the result of a lottery and … it is difficult to see how 'poor health' in the sense of someone wanting to hire only 'healthy' workers has any relevance here

The LNT is a method of calculating the damage in cases where a population is exposed to a given amount of radioactivity. It is a very simple method, whereby all the radiation doses to which the population has been exposed are added up and then divided by 20 to give the number of cancer deaths. So, for example, if 100 million people are exposed to 1 millisievert per year for twenty years the calculation would be as follows: one hundred million times 1 millisievert per year times 20 years equals two billion millisievert, which equals 2 million sievert. Dividing 2,000,000 by 20 gives 100,000. Hey presto and you've got your number of cancer deaths..

No doubt you're wondering why this division by 20? What is it based on? Well, among the survivors of the atom bombs of Hiroshima and Nagasaki, there was a group who had received an average of 1 sievert each in a single dose. As we shall see, that's a large amount. In this group the percentage of people contracting cancer was 38 percent instead of the 33 percent observed in a comparable non-exposed group. So 1 sievert means 5 percent more people die of cancer. This single piece of data forms the basis for the calculation 1 sievert = 5 percent (1/20) extra cancer risk.

But this is a nonsensical calculation. Incremental exposure is less damaging than a dose that is given all at once. In other words, the phenomenon of hormesis is totally ignored. Sanders argues that ionising radiation in small amounts is actually healthy, just like regularly running or fasting moderately. It can actually decrease the cancer risk by 10 to 30 percent compared to no extra radiation at all. So where the cancer risk is, say, 30 percent, a limited amount of radiation could cut this to 27 percent (i.e. by 10 percent).

Thermal baths

But what is meant by a limited amount in this context? Natural background radiation in areas that are not extremely rocky amounts to some 2.5 millisievert a year. A CT-scan amounts to 50 millisievert at once. Sanders calculates that the hormetic range runs to 200 millisievert a year, or a single dose of 100 millisievert if the radiation involved is of the 'light' kind, namely electrons and gamma photons. The inhabitants of the area around Chernobyl (only animals now) get 6 millisievert per year. They seem to thrive.

In Ramsar in Iran the soil produces a lot of radon, and the background radiation there reaches values of up to 700 millisievert per year. According to the LNT hypothesis, living there for 20 years would lead to about 100 percent of the people dying of cancer, but the villagers there seem to suffer from nothing except a slightly more active immune system.

Radiation test after the Fukushima disaster (photo: Kim Kyung-hoon / Reuters)

Sanders presents a lot of evidence for his thesis. As someone who has studied pseudosciences for a number of decades, I have come across a great many books and articles with lots of references that on closer inspection turn out to be misquotations or selective quotations or simply irrelevant or nonsensical. But Sanders cites over 1,000 papers in first-rate scientific journals, as far as I can tell. The evidence he presents consists of many examples where one can estimate the cancer risk as function of a low dose, for example workers in the nuclear industry who wear badges indicating the degree of radiation to which they have been exposed. Data about visitors of thermal baths (which contain a lot of radon) are another source of information. There are many experiments with animals and in vitro cells. All in all, I think that Sanders' book cannot be dismissed out of hand and merits serious study.

Repair mechanisms

How could the LNT-hypothesis have remained unchallenged for so long? I think that a simple theory of cancer was the basis for this belief. Cancer, it was thought, was caused by one simple mutation setting the cell on a fatal path. Each ionising particle (gamma photon, electron or alpha particle) has a certain small chance of starting a cancer process. Damage once done, cannot be undone, so the damage from ionisation is cumulative.

But this is not how cancer works, as is made clear in an excellent new book by Siddharta Mukherjee, *The Emperor of All Maladies: A Biography of Cancer* (Scribner, 2010). Mukherjee explains that from the late 1970s onwards there has been a growing insight into what happens in cells before they become full-blown cancer cells. Robert Weinberg and Douglas Hanahan wrote an article in January 2000 entitled ‘The Hallmarks of Cancer’, which summarized all the information science had collected in two decades.

Usually cells divide only when necessary. Inflammatory processes stimulate cell division when there is something that should be repaired, for example. The first step on the path to cancer is that a cell acquires an autonomous drive to divide. A gene (*ras* or *src* for example) that produces a molecular switch for cell division is damaged, with the result that the gene product becomes a switch that is stuck to ‘on’. Normally there are genes (such as *Rb*) whose products inhibit cell growth. The next step is that such a gene is damaged. Each cell has a suicide programme: in case of serious damage it will self-destruct. This is called apoptosis. Further mutations take out the genes that are responsible for this. Another factor is that cells usually can’t keep dividing ad infinitum – that’s why we age. But cancer cells are essentially immortal; they can go on dividing forever, and this is caused by another mutation. All of this would lead to the growth of a small tumor. But growing cells need food and oxygen, and if the tumor cells cannot get these, it will slow them down. Many tumors have acquired the capacity to stimulate the growth of blood vessels. Even with all these changes the tumor would remain a lump that grows in one place only. The final and sixth step in the transformation into cancer is the ability to migrate to other organs.

There are many mutations that lead to this result, and there are more than a hundred different types and subtypes of cancer cells. An analysis of the DNA of cancer cells usually shows a bewildering maze of mutations, not just base pairs that have changed from A-T to G-C or vice versa, but whole chunks of genes missing or transposed to other places. But to the best of our knowledge a full- blown cancer requires the six steps of Weinberg and Hanahan. So if someone is exposed to a mutagenic influence of any kind, the chance of getting cancer increases, but one can never say that a single mutation is ‘the’ cause of cancer. Only when the mutagenic influence is permanently present at a high level (such as a chronic inflammation, strong radiation or continuous exposure to certain chemicals) can one point the finger at ‘the’ cause.

In all of this the role of repair mechanisms remains relatively unexplored. It is known that in some kinds of hereditary breast cancer one particular repair mechanism is crippled. The relevance for hormesis is that radiation at a low level seems to stimulate the activity of repair mechanisms. If a cell is crossed by a light particle causing many ionisations, the repair activity is enhanced. It seems, according to Sanders, that the cell signals to its neighbours to warn them, so that not only the affected cell has an improved resistance to further attacks, but a large number of nearby cells as well. The availability of more anti-oxidants persists for a few hours, increased numbers of repair enzymes remain in circulation for several days, and improved apoptosis is observable for several months. The net effect of these increased defences is the same as that of regular exercise, restricted food intake and eating many different kinds of plants: the protective effects of defence against low- level stress exceed the damages of the stress itself.

But serious accidents don’t happen out of the blue. They are often the result of ignorance, sloppiness, and executives who think only about cost savings without any idea of the technology they supposedly direct

Road locomotives

So what can we conclude from all of this? The LNT–hypothesis is extrapolated to include low doses, but there is no proof for it at all. For regulatory authorities, LNT makes it easy to impose strict regulations on the use of nuclear energy. These rules are extremely costly, but easy to check. The situation is not dissimilar to that in the early days of the automobiles. The British authorities were so afraid of the (admittedly potentially lethal) risks posed by cars on the roads that they stipulated (in 1865) that a man with a red flag should walk in front of these so-called road locomotives. It was only in 1896 that the law was relaxed slightly and the maximum speed for automobiles increased to that of bicycles (22 km/h).

But while seeming benign such severe rules (“better safe than sorry”), can result in real damage. After the Chernobyl disaster, radiation took only a few lives. However, many cases of thyroid cancer were found. They demonstrate what the real problem was, namely an irresponsible safety culture. Simple iodine tablets could easily have prevented all these cases of thyroid cancer. Still, thyroid cancer is easy to treat and altogether only nine cases were fatal. About 800,000 ‘liquidators’ worked in Chernobyl, but until 1998 (Sanders gives no more recent results) the number of cancer cases among them was 20 percent *below* that of the population in general. However the panic and fear of radiation drove over 1,000 people to suicide. More than 100,000 women – maybe even twice as many – aborted a wanted child out of fear of possible radiation-induced congenital defects. Hundreds of thousands of people were forced to move, and many of them became destitute. The costs of the disruptions to society were enormous.

Some proponents of LNT have put forward arguments against hormesis. That’s fine of course, but some of the pro-LNT arguments I have seen seem singularly unconvincing and even smack of pseudoscience. One example is the so-called healthy worker effect (HWE). The HWE argument says that groups of people exposed to radiation, such as people working in the nuclear industry, are not representative of the average population, because they are selected for their good health in the first place and in addition their health is more carefully monitored than that of most people. Sanders observes that there is not a shred of evidence for this thesis. I might add that what is known about the genesis of cancer as described above also militates against the idea that being healthy somehow involves a lower cancer risk. Cancer is largely the result of a lottery and one can only reduce the risk by habits such as mentioned above, but it is difficult to see how ‘poor health’ in the sense of someone wanting to hire only ‘healthy’ workers has any relevance here. There is simply no evidence for HWE in relation to the effects of low amounts of radiation. The LNT-proponents cannot reasonably defend their unproven theory by another unproven theory.

Sanders’ book about radiation hormesis has converted the Canadian environmental activist Lawrence Solomon. He used to be a fierce opponent of nuclear energy. After reading Sanders’ book he came to the conclusion that the slogan ‘There is no safe level of radiation’ is incorrect. I recommend the book. It is expensive, but if you know where to look it can be downloaded as a free pdf.

Permit me to make a final remark about nuclear energy. There are many problems with nuclear energy, and a major concern is the possibility that a serious accident will affect many millions of people, with much more than just low-level radiation. But serious accidents don’t happen out of the blue, like a meteorite falling from the sky. They are often the result of ignorance, sloppiness, and executives who think only about cost savings without any idea of the technology they supposedly direct and who underestimate the capacity of people to make mistakes. They are the people who think that if something fishy works out fine half a dozen of times, it will also work out fine millions of times. But the solution to this is not costly enforcement of LNT-based regulations to ever stricter levels. Safety rules should rely on realistic, scientifically-based assessments of the risks of radiation, rather than irrational fears based on ignorance.

Who is Jan Willem Nienhuys?

Jan Willem Nienhuys, a retired mathematician, is Secretary of the Dutch organisation Skepsis (scientific evaluation of extraordinary claims) and a Fellow of the Committee for Skeptical Inquiry (CSI). He lives in Waalre in the Netherlands. His email adres is j.w.nienhuys@tue.nl. This article was first published in Dutch in Skepter, Winter 2010.

Contributions

I have been following the discussion on the risks of radiation and nuclear power since the early sixties. This discussion is governed by fear. Unless this fear is adressed no consensus can be achieved. This fear is increased by the fact that information given by the operators and authorities after nuclear acccidents can not be trusted. The side bar "Serious accidents don't happen out of the blue" forms a basis for further discussions.

The risk of radiation can not be treated in isolation. The linear hypotheses is but a bad appproximation. In a reasonable model the influence of other carcinogenic substances that are consumed and the quality of the immune system should be included. The effectiveness of the immune system depends on diet and livestyle

Only smoke from tabak is a carcinogen with a proven effect in humans Even so 30 % of the western population dies of cancer and there is no model that can attribute the rest to the different carcinogens.

Willem Jan Oosterkamp

There is new research out of the Los Alamos National Lab that was performed underground at the WIPP facility (2,000 Ft underground) that showed some organisms did not grow in the reduced cosmic radiation environment while they did grow with some low level radiation supplied. Definite support for hormesis.

Linda D

A refreshing display of sound reasoning. Most problems are amenable to similar treatment. The obstacle, as it is in the case of nuclear energy, is that the general population is essentially incapable of accurately following the path of quantitative logic. The path of emotion and pre-conceived notions is much more accessible. Thus I cannot share Mr. Verwer's optimism regarding the future disappearance of the red flags, although we can remain hopeful.

William Edwards

Good to reading all this. Scientific work and its ever continuing progress will help us improving rationalisme. One day the red flags will disapear and nucleair energy can deliver its promise to mankind. These studies certainly contrbute to it. Thank you for letting us know.
Jannes Verwer

Jannes Verwer

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