Nuclear health hazards

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2016

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July 2016

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Acknowledgements
The author would like to thank Dr Ian Fairlie for reviewing the radiological part of this report and for his suggestions, Angelo Baracca for his suggestions, and Stephen Thomas and John Busby for their comments. The author notes that this report does not necessarily reflect their opinion.
The author would like to thank Mali Lightfoot, Executive Director of the Helen Caldicott Foundation, for her valuable suggestions and comments.

Errors are the responsibility of the author.

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Summary

Widely divergent views exist on the health hazards posed by nuclear power. This study assesses a number of reports from the nuclear industry on this issue, and balances the official statements against empirical evidence, scientific logic and basic natural laws. Political, military and economic aspects are not addressed although these certainly underlie the differences.

Generation of man-made radioactivity

A unique feature of nuclear power is the generation of human-made radioactivity. The amount leaving the reactor in spent fuel and other materials is a billion times greater than what enters the reactor in the fresh nuclear fuel. During the past 60 years, civil nuclear power has generated some 11 million times more anthropogenic radioactivity than was released by the Hiroshima and Nagasaki atomic bombs in 1945. This amount is still present in the human environment, at countless sites, and it is still rising at a current rate of about 300 000 bomb equivalents a year.

Dispersion of natural and human-made radioactivity

A nuclear power plant is not a stand-alone system: a sequence of industrial processes is required to extract uranium ore from the earth's crust, and to fabricate nuclear fuel from it that can be used in nuclear reactors. Another, larger, series of industrial processes is required to manage the radioactive waste safely. Jointly these processes are called the nuclear process chain; in fact the nuclear system may be the most complex energy system ever designed. When discussing the benefits and adverse effects of nuclear power the complete nuclear process chain should be taken into account.

Large masses of naturally-occurring radioactive materials are mobilised into the biosphere during the mining of uranium ores, especially radon and thoron gases. Massive amounts of human-made radioactive materials are routinely released during the normal operation of nuclear reactors and reprocessing plants. In addition to routine discharges, radioactive materials are dispersed as a result of technical failures and accidents. Radioactive effluents include gases, vapours, aerosols, dusts, particulate matter, and radionuclides dissolved in aqueous liquids, including very large volumes of water which is itself radioactive (tritiated water). In addition solid radioactive materials end up in the environment, such as scrap and rubble. Dispersion may also occur from the incineration of radioactive waste, the intentional or unintentional burning of materials contaminated by radionuclides for heating or cooking, and by forest fires in contaminated areas.

Biomedical aspects of radioactive contamination

Nuclear radiation strongly interacts with cellular matter. Radiation destroys or modifies biomolecules such as DNA, which may cause harmful effects in an organism. Alpha and beta radiation can be blocked by clothing and skin and therefore may seem relatively harmless. However, alpha and beta-emitting radionuclides are extremely dangerous inside the human body, for living cells are not protected by the skin or clothing. The alpha and beta rays cause a large number of damaged biomolecules inside living cells. Moreover, several radionuclides accumulate in specific organs causing locally high radiation doses.

Contamination by radioactive materials involves more than exposure to radiation alone. In addition to the radiation, chemical factors are important in judging the hazards of radioactive substances inside the body, such as:

- biochemical properties of the radioisotope itself and of its decay products
- biochemical reactions initiated by the ionizing radiation of the radioactive decay, via primary and secondary ions
- biochemical reactions initiated by the energy transfer of the recoil and of the secondary electrons.

Many radionuclides released into the environment enter the food chain and drinking water and as a result people in the contaminated areas are internally exposed to those radionuclides for prolonged periods. In addition people are exposed to skin doses and by breathing radioactive gases and particulate matter. Health effects caused by prolonged exposure to a gamut of radionuclides are not investigated. What are the synergistic biomedical effects?

The classical radiologic models discern deterministic (also called non-stochastic) effects and stochastic (also called probabilistic) effects. The former occur after exposure to extremely high doses of radiation and become evident within hours to weeks (ARS: Acute Radiation Syndrome), the latter are caused by lower doses and can have incubation periods of years to decades.

Relatively recent studies have proven the existence of 'non-targeted' and 'delayed' radiation effects. These effects had probably been observed in earlier studies but had gone unrecognised as they fell outside the then accepted paradigm of radiation effects. The observed phenomena pose many fundamental questions to be answered and will result in a paradigm shift in the understanding of radiation biology.

Observed health effects

Due to the long incubation periods it may take years before stochastic health effects become observable. In the years since the Chernobyl disaster in 1986 a great variety of diseases have been reported in the contaminated areas in Ukraine, Belarus and Russia: cancers and non-cancer diseases, lethal and non-lethal diseases, such as:

- multimorbity classified as radiation-induced premature senescence
- cancers and leukaemia
- thyroid cancer and other thyroid diseases
- damage to nervous system, mental disorders
- heart and circulatory diseases
- infant mortality, stillbirths, low birth-weight
- congenital malformations
- endocrinal and metabolic illnesses
- diabetes
- miscarriages and pregnancy terminations
- genetic damage, hereditary disorders and diseases
- teratogenic damage, such as: anencephaly, open spine, cleft lip/palette, polydactylia, muscular atrophy of limbs, Down's syndrome.
- chromosomal damage
- radiation-induced cataracts
- vascular vegetative dystony (the "new Chernobyl syndrome")

Epidemiological studies in Germany and France proved a relationship between the increased incidence of childhood cancers and leukemia and the living proximity of the childern's homes (for childern under 5 years old) to normally operating nuclear power plants. These effects cannot be explained by the radiological models applied by the nuclear industry.

Limitations of the current radiological models

The radiological models used by the nuclear industry are based on the effects of gamma- and X-ray radiation from sources outside the human body. UNSCEAR states: "The single most informative set of data on whole-body radiation exposure comes from studies of the survivors of the atomic bombings in Japan in 1945. The atomic bombing exposures were predominantly high-dose-rate gamma radiation with a small contribution of neutrons."

The models are based on studies that started about five years after the atomic bombings, so the deaths during these first five years are not counted.

What was the original purpose of these 60-year-old models? To estimate the acute radiological risks for

military personnel in the Cold War with the threat of nuclear weapons during the 1940s and 1950s, at a time no civil nuclear power plants existed? Or to estimate the health hazards for millions of people in 21st century posed by chronic exposure to a vast number of radionuclides discharged by hundreds of civil nuclear power plants over the course of decades?
The methodology and scope of these studies do not comply with present scientific views and insights that are based on the vast amounts of emprirical data that became available during the past decades. Epidemiological studies proved that the existing exposure and health risk models are unable to explain the empirical observations, so the models should be revised.
During the disasters of Mayak, Chernobyl and Fukushima amounts of radioactivity equivalent to many thousands of exploded Hiroshima bombs have been discharged into the environment.
What are the effects if the exposure is chronic as a result of continuous intake (food, water), inhalation of radioactive gases, dust and aerosols? What are the effects of bioaccumulation in the food chain?

Like any scientific model the radiological models have their inherent limitations, because a model is by definition a simplication of the reality. In addition a model has also limitations due to the basic assumptions and to the choice of the input parameters. Models are only usable within the boundaries of a well-defined system. How are the radiological system boundaries defined?

Entanglement of interests

Physically an NPP is part of an intricate network of industrial activities. In turn this technical system is part of a complex of interests, with miltary, political, economic, social, environmental and health aspects. For reason of the diversity of interests it is not simple for the public and policy makers to get a reliable overview of the nuclear energy complex as part of the society.
Information concerning civil nuclear power to the general public and to policy makers is globally dominated by the International Atomic Energy Agency (IAEA).

IAEA

The IAEA is an international autonomous organization, established on 29 July 1957 independently of the United Nations, through its own international treaty with the member states.
The IAEA has two mandates: one as *watchdog* to prevent malicious use of nuclear technology – a role primarily restricted to guarding against illegal nuclear weapons production and proliferation risk –, the other as *promotor* of nuclear power. Its official publications have to be approved by its 159 member states. For above reasons the IAEA cannot be considered to be an independent scientific institute.

ICRP and UNSCEAR

Two other international nuclear-related institutes, the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have strong connections with the IAEA. The main task of the ICRP seems to be the formulation of a legal framework for authorities and politicians for how to cope with any liability which may arise from planned exposure of people to radiation and/or radioactive materials in medical, scientific and technical applications. The work of UNSCEAR seems to be focused on exposure to external radiation chiefly from natural sources. The impression is given that UNSCEAR (and also ICRP) care more about radiation from natural sources than from human-made sources.

Role of the WHO

According to an agreement between the International Atomic Energy Agency and the World Health Organization (UN Res. WHA12-40, 28 May 1959) the WHO cannot operate independently of the IAEA on nuclear matters. As a consequence the official reports of the WHO on nuclear health hazards do not deviate from the IAEA viewpoint. With respect to health effects of exposure to radiation and radioactive materials, the IAEA, UNSCEAR and WHO are speaking with one voice.

Significance of the Second Law of thermodynamics

All observable changes in our world are subject to the Second Law of thermodynamics. In the publications of the nuclear industry we found no evidence of awareness of the consequences of the Second Law. One of the important Second Law phenomena is usually called ageing: as a result of unavoidable spontaneous processes materials and structures deteriorate with time; this process is exacerbated by nuclear radiation. The consequences of ageing for nuclear safety and health hazards are significant, especially with regard to:

- leaks and unintended discharges
- risks of large nuclear accidents
- storage of radioactive waste in temporary storage facilities or shallow burial disposal sites
- spent fuel cooling pools and dry cask storage of spent fuel
- lifetime extensions of reactors.

In addition the highly optimistic presentations of the potential of the next generation of nuclear technology, promising inherently safe nuclear power, nearly unlimited energy resources, less radioactive waste and moreover shorter-living radioactivity, are evidence of ignorance of the Second Law. These concepts, most of them originating from the 1950s and 1960s, are implicitely based on the assumptions of the availability of perfect materials and of 100% perfect separation processes, both assumptions are in conflict with the Second Law. The conclusion has to be that these 'advanced concepts' are inherently infeasible.

Downplaying and denial of health effects of radioactive contamination

From the reports of the IAEA, UNSCEAR and WHO on the subject of health effects of the disasters of Chernobyl (1986) and Fukushima (2011), a picture emerges of the nuclear industry marked by downplaying and even denying health effects caused by exposure to radiation and contamination by radioactive materials. The Mayak (Kyshtym) disaster in the East Ural in 1957 has long been kept secret and is still being concealed.

Apparently the nuclear industry takes the view that if the relationship between exposure to radiation and a specific health effect in a particular person cannot directly be proven within a short timespan, the cause of the observed disease *must* be non-nuclear. This view is not backed by any epidemiological proof nor other evidence. Non-cancerous diseases are not recognized as radiation-induced health effects, attention is paid mainly to acute radiation syndrome (ARS, radiation sickness). According to IAEA/UNSCEAR/WHO the death toll of Chernobyl was less than 50 persons. Other institutions came to estimates of 100 000 to 1 million deaths, taking into account all health effects caused by exposure to radioactivity.
IAEA, UNSCEAR and WHO place full reliance on radiological models for assessment of exposure doses and of dose-effect relationships, with little or no input of empirical evidence that became available after the conception of the models in the 1940s and 1950s. Biochemical behaviour of radionuclides inside the human body are not included. Chronic exposure to radionuclides inside the body, via ingestion (food and water) and inhalation (gases, dust) are not covered by the investigations either.

In the publications of IAEA/UNSCEAR/WHO we found no indications of awareness of the implications of the German and French epidemiological investigations (and many other studies) that found a significant connection between the incidence of childhood cancer and the proximity of normally operating nuclear power plants. These incontestable results cannot be explained by the models and way of reasoning of the nuclear industry. From a scientific point of view the conclusion should be: the models are inadequate and have to be rivised.
A strong economic component can be sensed in the assessments, the economic consequences of nuclear disasters appear to be considered more serious than detrimental health effects and human suffering.

No reliable investigations

Reliable assessments of the health effects of the Chernobyl and Fukushima disasters are hampered by several factors, such as:

- poor detectability of many dangerous radionuclides
- long latency period of health effects from exposure to radioactivity, coupled to a short time horizon of the investigations
- limited measurements of radioactive contamination
- limited scope of the IAEA and WHO investigations
- absence of adequate epidemiological studies
- secrecy of medical data
- short time horizon of the nuclear institutions
- economic interests.

Elementary scientific flaws

Remarkable are the methods used by the IAEA, UNSCEAR and WHO in their reports on the consequences of the disasters of Chernobyl and Fukushima. When dicussing the health effects caused by exposure to radioactive materials, these institutions commit elementary scientific flaws in their reports.

Missing proofs

We found conclusions that are not backed by empirical evidence. Detrimental health effects are attributed to 'radiophobia', 'fear of unknowns', 'bad lifestyle'. In the reports of the IAEA/UNSCEAR/WHO the proofs of above assertions are missing: no investigations are performed or reported which would underpin these statements.

According to the radiological paradigm of the IAEA/UNSCEAR/WHO non-cancerous diseases are not considered as possible ill effects caused by radioactive contamination, but are attributed to other factors.

Models prevail over empirical evidence

Empirical data that deviate from the applied radiological models are ignored and observations of detrimental effects are attributed to non-nuclear causes if they don't fit the theoretical models used. If the nuclear industry cannot *prove* that there are no detrimental health effects of exposure to radioactive materials and radiation, a reasoning based on models is *not* a scientific proof.

No scientific discourse

In the IAEA/UNSCEAR/WHO reports we found no discussion of scientific reports with results diverging from their own view; the titles of such reports are not even mentioned. Avoidance of a scientific discourse might be seen as a serious flaw of any scientific investigation, the more so in case of a complex matter as the consequences of a nuclear disaster.

Critical opinions are, without reference to the sources, dismissed as 'unscientific', 'myths' or 'erroneous'. The IAEA/UNSCEAR/WHO fail to elucidate their meaning of these terms and to found their qualifications on scientific arguments, thus avoiding any discussion of the scientific arguments behind the diverging opinions.

Problems for the future

Most likely the frequency and seriousness of releases of radioactive materials into the environment will increase with time due to several factors, such as:

- Increasing amounts of radioactive materials are piling up in a growing number of temporary storage facilities. Because no definitive and safe disposal facilities are operational a fraction of these materials will escape into the environment due to inherent deficiencies of technical systems and human behaviour.
- Unavoidable deterioration of materials and structures of spent fuel elements and of temporary storage facilities of radioactive wastes, as a consequence of the Second Law of thermodynamics, enhanced by the nuclear radiation from the waste. Due to these ageing processes the fraction of the radioactive waste escaping into the environment likely will increase with time, as well as the risks for large nuclear accidents.
- Escalating costs and a growing backlog result in increasing economic pressure, potentially exacerbated

in case of an economic decline. These factors may cause:

  - decrease of safety-related investments and staff at nuclear power plants and possibly also at other nuclear facilities
  - relaxation of official discharge and clearance standards and regulations
  - less frequent and less independent inspections
  - increasing tendency to conceal failures, leaks and shortcomings
  - search for cheaper ways, and consequently less effective ways, to store increasing amounts of radioactive waste

- Illicit trafficking likely will increase as a consequence of above mentioned factors. Illegal trade and smuggling of radioactive materials and equipment is already a significant problem, little numerical data have been published.
- A related problem is the illegal dumping of radioactive waste at sea or in sparsely habitated regions.
- Nuclear facilities are vulnerable to terroristic suicide attacks, possibly initiating severe accidents.
- Severe accidents could also be initiated by hostile actions in an armed conflict anywhere in the world. The consequences of an accident like the Chernobyl and Fukushima disasters do not stop at the national borders.
- Postponing adequate waste management solutions to the future for economic reasons increases the risks of nuclear terrorism: dirty bombs dispersing radioactive materials or even primitive nuclear explosives made from MOX fuel. The risks may be growing by the increasing threat of terroristic organizations.
- Accidental and inadvertent releases of radioactivity into the environment, including large-scale accidents, can also be caused by natural disasters. As growing amounts of radioactive materials are present within the human environment and adequate actions are longer delayed, the risks of disasters grow and the released amounts may grow as well.
- Nuclear power plants that are beyond their original design lifetime are now in their wear-out phase, characterized by a growing failure rate of technical systems. Lifetime extension greatly enhances the risks of large-scale accidents, their frequencey as well as their severity. The same holds true for the ageing spent fuel cooling pools, high-level waste storage facilities and reprocessing plants. This development comes on top of the unpredictable risks of natural disasters.

Flexibility of regulations

Under economic pressure regulations on allowed concentrations of radionuclides in drinking water and food are relaxed by factors 100, 1000 or more, without scientific and medical arguments. This causes a vast increase of contamination by radioactivity of hundreds of millions of people. This effect comes on top of the increasing inventories of radioactive materials in nuclear installations and the deteriorating materials and structures containing the radioactivity. In addition inspections and quality controls may be scaled down, likely also for financial reasons.

Nuclear power and society

From the official publications of the nuclear industry and its associated institutions emerges a picture of their way of thinking and of communicating with the general public. Some characteristics of that picture are:

- entanglement of interests
- prevailing economic preferences
- systematic downplaying and denial of nuclear health hazards, using questionable methods
- unrealistic believe in technological possibilities in the future.

A preponderant factor causing increasing health hazards in the future may be the ‘living-on-credit’ culture within the nuclear industry, featuring systemic postponement of radioactive waste management actions to the future.

Introduction

Widely divergent views exist on the health hazards posed by nuclear power. The nuclear industry and its associated institutions and organizations assert that nuclear power is the safest known energy system. Other parties report on serious health harm as a result of nuclear activities, affecting millions of people.

This study assesses the way the nuclear industry reports on issues of safety and health hazards of nuclear power, and tests their statements against empirical evidence, scientific logic and basic natural laws. Political, military and economic aspects are not addressed.

Nuclear power has a unique feature no other energy system has: the generation of human-made radioactivity. The mobilisation of natural radioactivity and the generation of human-made radioactivity are the sources of the health hazards addressed in this study.

The first four chapters of this report briefly address factual information on:
- generation of human-made radioactivity
- dispersion pathways of radioactive materials from the nuclear system into the environment
- observed health effects of radioactive contamination
- limitations of the radiological models applied by the nuclear industry.

The fifth chapter adresses the entanglement of interests of three globally operating nuclear organizations: the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP). Furthermore the role of the World Health Organization (WHO) is discussed with regard to health hazards of nuclear power.

Chapter 6 briefly assesses the downplaying and denial of health effects of radioactive contamination as a result of the Chernobyl and Fukushima disasters in the reports of the IAEA, UNSCEAR and WHO. This assessment is based exclusively on quotes from the official reports, and from critical reports from scientific institutions.

A separate Chapter 7 scrutinizes the scientifically questionable methods applied in the official reports of the IAEA, UNSCEAR and WHO on the health effects of Chernobyl and Fukushima.

Chapter 8 addresses the flexibility of nuclear regulations and exposure standards under pressure of financial interests.

Chapter 9 addresses the possible health hazards in the future, posed by the radioactive wastes piling up in the human environment, and by the way the nuclear industry handles this issue.

President John F. Kennedy in his Address to the Nation on the Nuclear Test Ban Treaty, 26 July 1963:

> *"Even then, the number of childern and grandchildern with cancer in their bones, with leukemia in their blood, or with poison in their lungs might seem statistically small to some, in comparison with natural health hazards. But this is not a natural health hazard – and it is not a statistical issue. The loss of even one human life, or the malformation of even one baby – who may be born long after we are gone – should be of concern to us all. Our childern and grandchildern are not merely statistics toward which we can be indifferent."*

1 Generation of radioactivity

The nuclear energy system

The technical assessment of the potential dispersion of radioactivity into the human environment is based on a life-cycle analysis (LCA) from cradle to grave of the complete system of industrial processes which makes nuclear power possible. The nuclear process chain consists of three sections:

- *Front-end*: comprising the industrial processes needed to produce nuclear fuel from uranium ore.
- *Mid-section*: comprising the construction of the nuclear power plant, and its operation, maintenance and refurbishments during its operational life.
- *Back-end*: comprising the industrial processes needed to manage the radioactive waste and to isolate it from the human environment as long as it remains radioactive. The back end includes the decommissioning and dismantling of the radioactive parts of the nuclear power plant and of other nuclear facilities.

The cradle-to-grave (c2g) period is defined as the timespan needed to finish the sequence of processes and activities from the start of the construction of a given nuclear power plant (NPP) through the definitive and safe disposal of the last kilogram of radioactive waste generated by that NPP. The c2g period covers an unprecedented time period of 100-150 years, according to the current views. Nowhere in the world has a nuclear c2g sequence ever been completed.
The LCA proves the chain of industrial processes and activities making nuclear power possible to be the most complex energy system ever designed. In addition the LCA uncovered a number of features and uncertainties that prove to be important for the health hazards of nuclear power now and in the future.

All but a few of current NPPs are operating in the once-through mode, without recycling of uranium and plutonium. A small number of NPPs use about 30% MOX fuel instead of enriched uranium. MOX stands for Mixed OXide, fuel in which the fissile uranium-235 is replaced by plutonium, that is recovered from spent fuel in a reprocessing plant.

Natural and human-made radioactivity

In the front end processes of the once-through nuclear chain, including the extraction of uranium from its ore, only naturally occurring radioactivity is involved: uranium and its decay daughters. In the mining and milling uranium ore uranium is separated from its radioactive decay daughters. The latter end up in the waste streams and are in chemically mobile and reactive form. This waste stream of mobilised natural radioactivity is discharged into the biosphere. The radionuclides enter the groundwater and are also dispersed as dust and fine particulate matter. Apart from their radioactivity uranium and its decay products are also chemically toxic. Often uranium ores also contain thorium and its radioactive decay products that are released into the environment in the same way.

No principal difference exists between natural and human-made radioactivity: radioactive materials occurring in nature emit alpha, beta and gamma radiation, and so do the radioactive materials generated in nuclear reactors. It is a misconception to think natural radioactivity is more, or less, harmful to humans than human-made radioactivity.
The main differences are that radioactive materials generated in a nuclear reactor consist of a complex mixture of radionuclides, isotopes of dozens of different chemical elements, which do not occur in nature. The half-lifes of the human-made radionuclides are relatively short compared to the naturally occurring radionuclides.

Generation of human-made radioactivity

Nuclear power, fission as well as fusion, is in one respect distinct from all other energy systems, namely, the generation of radioactivity. A nuclear reactor is a generator of heat and radioactivity, simultaneously, inextricably and irreversibly. This unique feature has far-reaching consequences.
The flow of radioactivity in the nuclear process chain starts with the mobilisation of natural radioactivity of the uranium ore and multiplies a billionfold by the generation of man-made radioactivity in the reactor. Unavoidably a part of the mobilised and man-made radioactivity will be released into the environment. The purpose of the back end of the nuclear chain is to minimise the discharges of radioactive materials into the human environment. Isolation from the biosphere has to last for thousands to millions of years.

Human-made radionuclides come into being during the fission process in the reactor. Three groups of the artificial radionuclides are commonly distinguished, according to their origin:

- Fission products: the light atoms originating from the fission of the heavy uranium and plutonium atoms. Atoms of nearly all chemical elements are present in the mix and a part of the fission products are highly radioactive.
- Transuranic actinides: atoms heavier than uranium, which are formed from uranium atoms by neutron capture. These elements, for example plutonium and americium, do not occur in nature and are highly radioactive and highly toxic.
- Activation products. Non-radioactive materials exposed to neutron radiation from the fission process become radioactive by neutron capture; examples are the zirconium of nuclear fuel cladding, the steel of the reactor vessel and the concrete of the structures surrounding the reactor.

Important are the following facts:

- Generation of nuclear power is inextricably and irreversibly accompanied by the generation of immense quantities of radioactivity.
- Radioactivity cannot be destroyed. Once generated, radioactivity cannot be influenced by any means.
- Radioactivity cannot be made harmless to living organisms.

The radioactivity of a given material decreases by natural decay only. For some components of the human-made radioactivity the decay rate can be measured in seconds to hours, for other components timeframes of years to millions of years are involved; the decay rate is specific for each kind of radionuclide.

Each nuclear reactor of 1 GWe power produces each year an amount of radioactivity roughly equivalent with 1000 exploded nuclear bombs of 15 kilotonnes, about the yield of the Hiroshima bomb. A nuclear reactor generates relatively more long-lived dangerous alpha-emitting radionuclides (actinides) than an exploding nuclear bomb, so the radioactive materials from a reactor are more dangerous than a comparable amount from a nuclear explosion. The current world inventory is the equivalent of more than 11 million nuclear bombs.

Broadly speaking human-made radioactivity ends up in two waste streams: spent fuel and other radioactive wastes. Spent fuel has a relatively small volume and contains roughly 90-95% of the human-made radioactivity; its residual heat generation lasts for hundreds of years. The other waste stream has a very large volume and contains the balance of the radioactivity, and consists of the operational waste from the processes of the nuclear chain. Massive amounts of radioactive waste are released when nuclear reactors and other radioactive contaminated facilities, including reprocessing plants, are decommissioned and dismantled.
Nuclear health hazards are caused by the dispersion of radioactive materials into the environment. Human-made radioactivity at the moment of its generation is chiefly contained in the spent nuclear fuel. Even after a cooling period of 100 years the specific radioactivity of spent fuel is still at such a high level that about 0.25 gram of it ingested or inhaled would mean a lethal dose to a human.

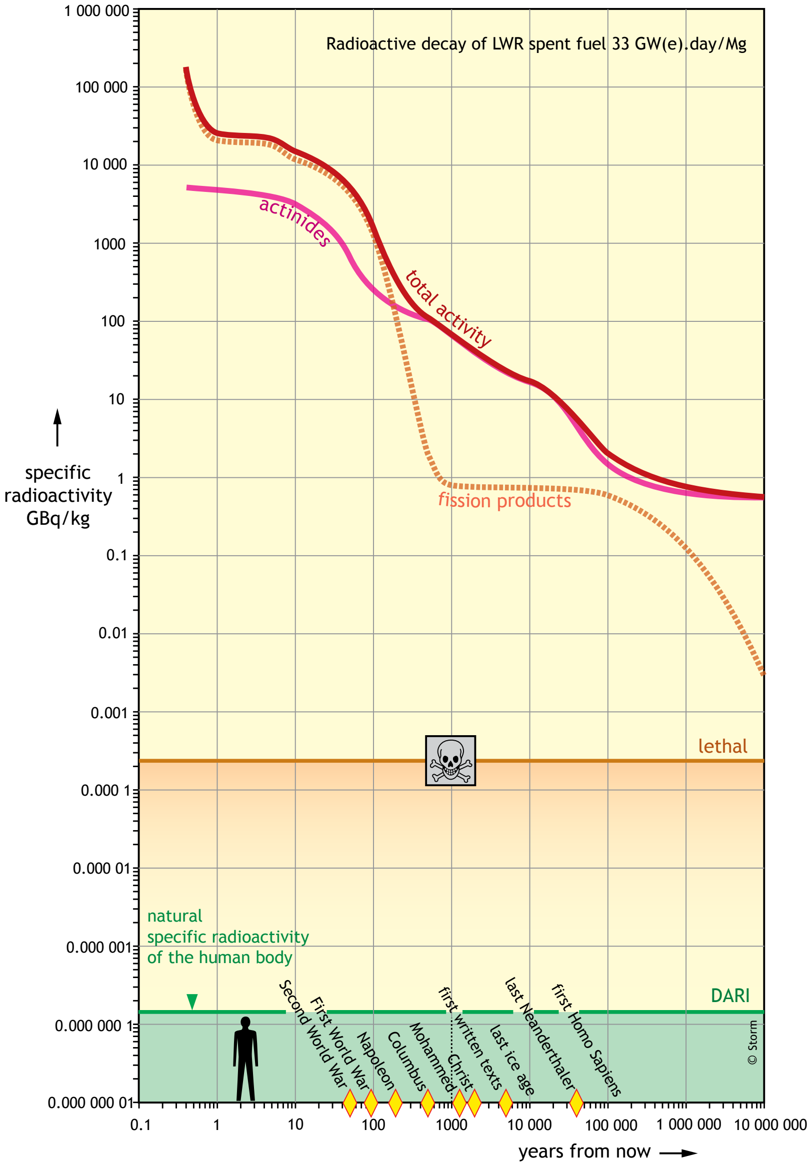

Figure 1

The specific radioactivity, in gigabecquerel per kilogram (GBq/kg), of spent fuel at a burnup of 33 GWe.day/Mg (gigawatt electric per metric tonne uranium) charged into the reactor. Nuclear fuel from current types of nuclear reactors usually has higher burnup (40-50 GWe.day/Mg) than the fuel this diagram is based on and consequently its specific radioactivity is higher. The contributions of tritium and carbon-14 are not included in these curves. Note that both axes have logarithmic scales. Each scale division denotes a factor ten. With linear time scales the horizontal axis would be about 100 kilometers long and the vertical axis some 100 million km.
On the horizontal axis a reverse historic timescale is indicated, to give an idea of the time frames involved. The green line indicates the natural radioactivity of the human body (143 Bq/kg). Sources: [Bell 1973], [Hollocher 1975], [JPL-77-69 1977], [Charpak & Garwin 2002].

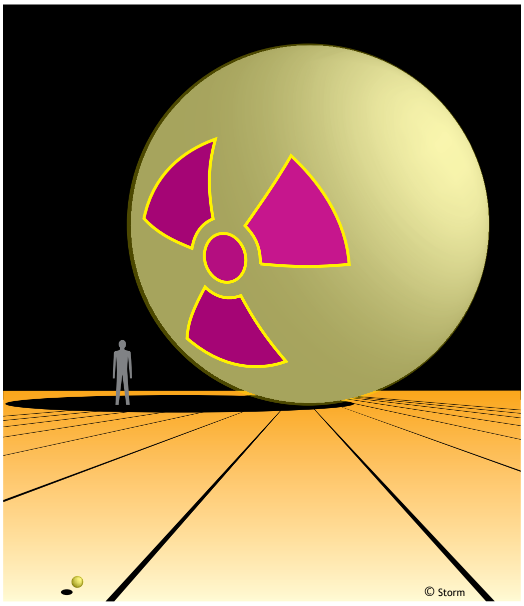

Figure 2

As a result of the fission process the radioactivity of the nuclear fuel irreversibly increases a billionfold. The pea in the foreground (diameter 1 cm) represents the original radioactivity of the nuclear fuel, the sphere in the distance with a diameter of 10 meter represents the radioactivity of the same amount of fuel 150 days after shutdown of the reactor. Based on data from: [Bell 1973] , [Hollocher 1975] and [JPL-77-69 1977].

Dispersion of human-made radioactivity

All radioactive wastes ever generated during the nuclear era are still stored in temporary storage facilities, in addition some are still dumped into the sea, lakes, rivers and uncontrolled landfills, intentionally and unintentionally. The temporary facilities are leaking all kinds of radionuclides into the environment at an increasing rate, due to the progressive deterioration of the materials and structures of the containment facilities.

Ever since the first nuclear reactors started operation in the 1940s, a definitive solution to the radioactive waste problem has been postponed to the future. Spills from corroding storage tanks and waste containers are polluting watersheds, rivers and the sea. An underrated aspect of civilian nuclear power is the size of the radioactive waste problem and its exponential growth over time. The global nuclear generating capacity grew from tens of megawatts in the 1950s to hundreds of gigawatts today, a factor of 10 000. The generation of human-made radioactivity continues, adding some 300 000 nuclear bomb equivalents to the world inventory each year.

In view of the enormous amounts of radioactivity involved in the reactor operation and in the downstream processes, even the escape of a tiny fraction could involve large amounts of radioactivity with serious public health consequences. If just 0.1% of the radioactivity content were discharged into the human environment, that would still mean one nuclear bomb equivalent per year per reactor. Broadly three categories of discharges of radioactive materials into the human environment can be discerned:

- authorised routine releases, occurring continuously at every nuclear facility
- unauthorised releases (leaks, accidents), occurring at random at nuclear facilities
- large-scale accidents.

The chance of exposure to radioactive substances and ionizing radiation from human-made sources is approaching 100%. In the Northern hemisphere people can be quite sure they are being exposed to human-made radioactivity. The question is not *if* the questions are: *how much* radioactivity and *which radionuclides*?

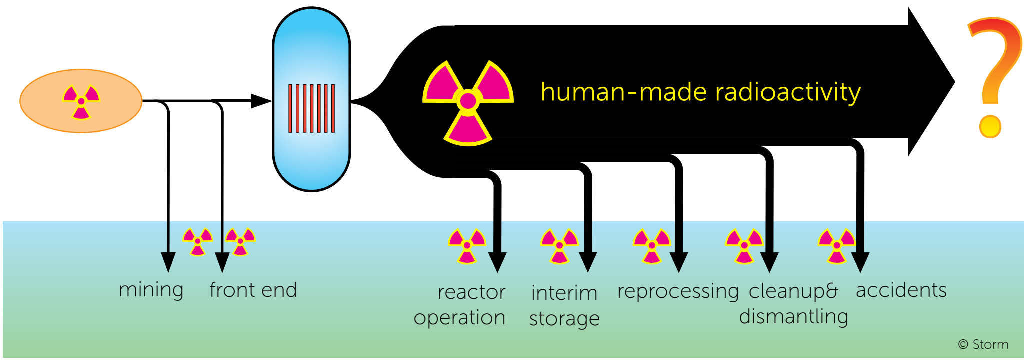

Figure 3

Symbolic outline of the radioactive discharges into the environment of the nuclear system. Before nuclear fuel enters the reactor, the releases comprise naturally occurring radionuclides. Spent fuel leaving the reactor contains human-made radioactivity a billionfold of the amount of radioactivity that enters the reactor. A significant part of the human-made radioactivity is discharged routinely into the human environment via gaseous, liquid and solid effluents and may enter the food chain. In principle the remaining wastes generated are to be packed in containers and isolated from the biosphere for indefinite periods; where, when and how this would be achieved is still an open question, symbolised by the query. In practice unauthorized and unplanned discharges occur at all points in the nuclear process chain.

Authorised routine releases

The nominally operating nuclear process chain routinely discharges radioactive substances into the environment, in the front end processes, during the reactor operation as well in the back end processes. A part of these operational releases is hardly avoidable from a technical point of view, but another part is accepted for economic reasons. Authorised discharges, occurring day to day, are officially classified as harmless; measurements of their magnitude are usually unknown in the public domain. However, epidemiological studies have proved routine releases of radioactivity by normally operating nuclear power plants to be harmful. These discharges are authorised under regulations based on models and standards that prove to be flexible under economic pressure. Authorised routine discharges comprise radioactive gases and dust and liquid effluents from processes of the nuclear chain.

Uranium mining

Uranium is highly toxic and attacks the inner organs, such as the kidneys. Studies show that uranium causes birth defects in foetuses and infants, and that the risk of leukemia is increased. Uranium mutates human DNA and chromosomes and deforms them [IPPNW U-4 2010]. Uranium is radioactive and decays into other radioactive elements. Radon and polonium, two of the decay products, are as toxic as uranium. The following diseases are scientifically proven through studies to have been caused by exposure to radon, uranium and the decay products of uranium: bronchial- and lung cancer, leukemia and other blood diseases, cancer of the bone marrow, stomach, liver, intestine, gall, bladder, kidney and skin, psychological disorders and birth defects [Schmitz 2007].

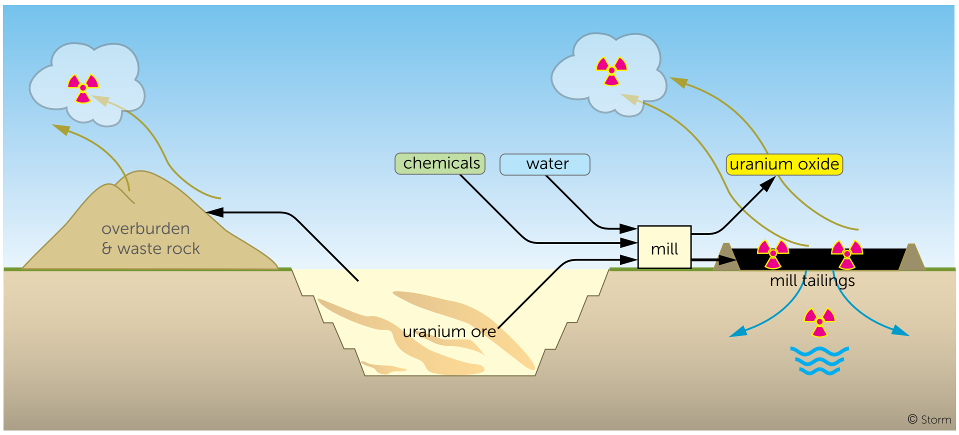

Figure 4

Outline of uranium mining plus milling, for explanation see text.

Extraction of uranium from the earth's crust comprises several processes. The ore body is uncovered by removing the rock surrounding it. Then the ore is mined and transported to the mill. By means of physical and chemical separation processes the uranium is extracted from the uranium-bearing rock and sold as uranium oxide. The waste stream, called mill tailings, a slurry containing the finely ground rock from which the uranium has been extracted, 1-3 tons per kg uranium, the used chemicals and lots of water, is dumped into large ponds. The liquids, containing dissolved radioactive and other toxic non-radioactive elements, evaporate and seep into the ground.

After depletion a uranium mine is usually abandoned. The mill tailings turn dry and the remaining pulverised materials, containing the radioactive decay products of uranium and other toxic elements from the ore, e.g.

arsenicum, in a chemically mobile form, are blown by the wind over large distances. The same holds true for the dust, also containing radioactive elements, blown off the large heaps of waste rock.
Striking is the following statement of the nuclear industry [WNA-04 2011]:

> 'Strictly speaking these (*mining and milling wastes*) are not classified as radioactive wastes'.

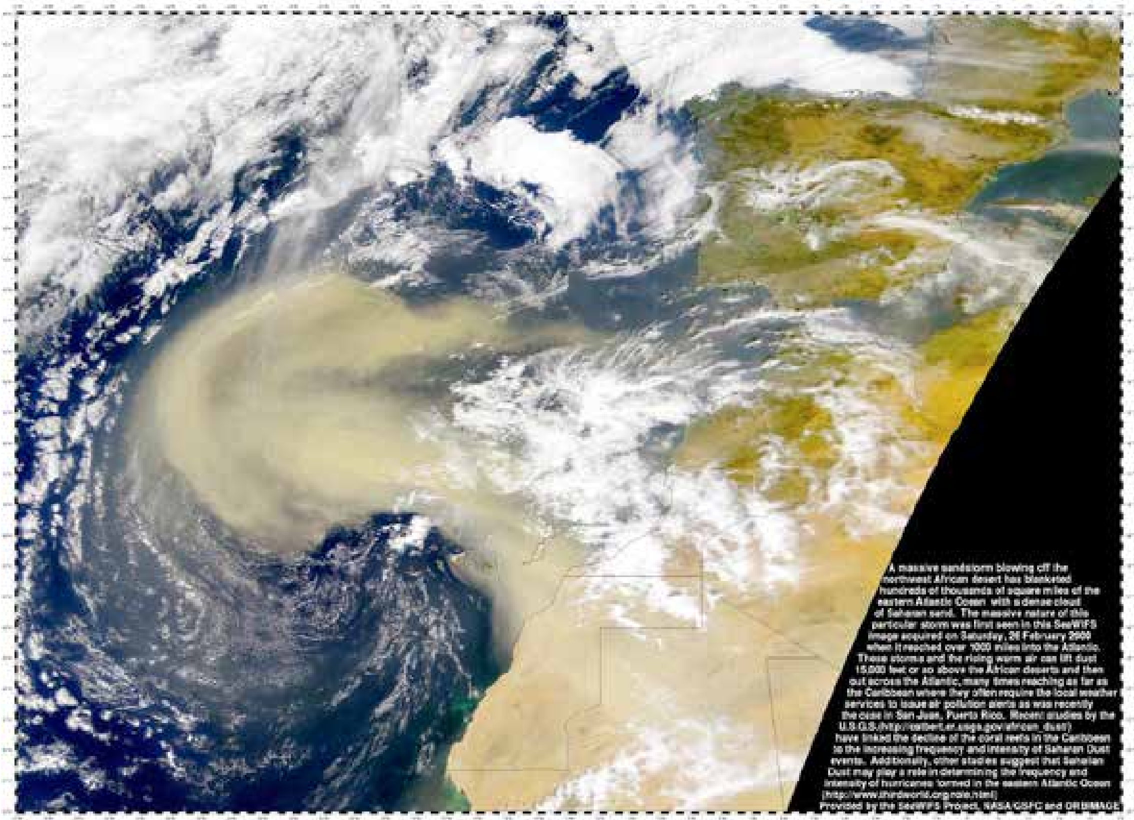

Figure 5

Dust storm from the Sahara into the Atlantic. A massive sandstorm blowing off the Northwest African desert has blanketed hundreds of thousands square kilometers of the Eastern Atlantic Ocean with a dense cloud of Saharan sand. This photo shows how far dust from arid areas, including radioactive dust from uranium mines, can be transported by the wind. Photo SeaWIFS/NASA.

Unplanned, unauthorised discharges

No technical system is perfect. Inevitably radioactive substances will leak out of the technical installations and equipment of the nuclear energy system and disperse into the environment. Leakages can be curtailed by application of high quality standards to the technical systems and a stringent inspection regime, but cannot be eliminated. Due to ageing, corrosion and wear the quality of materials and structures will inevitably deteriorate over time. Consequently the frequency and magnitude of spills and discharges from any given NPP tend to increase over time.
In principle any particular leak may be preventable but the occurrence of leaks in general is unavoidable and uncontrollable, as every engineer knows. Apart from the accidental spills from any nuclear facility there are unnoticed and practically 'invisible' releases. Leaks and small accidents at nuclear power plants and other nuclear facilities occur frequently and often go unnoticed for long periods. The amounts of discharged radioactive materials vary widely, but may be large in some cases. Examples of sources are:

- storage facilities of: depleted uranium, reprocessed uranium, plutonium and other actinides
- discarded radioactive components and materials

- nuclear power plants
- interim storage of spent fuel: cooling pools and dry casks
- interim storage and shallow burial of other radioactive waste
- reprocessing plants
- decommissioning and dismantling of nuclear facilities.

The processes of the back end of the nuclear chain are the most vulnerable to events causing massive discharges of radioactivity into the human environment because the involved radioactivity is millions of times greater than of the front end processes and the volumes of waste are thousands of times larger. Particularly vulnerable are all facilities containing spent nuclear fuel: reactors, spent fuel interim storage facilities and reprocessing plants. Because of the very long storage periods (which might extend to 100 years or more) of the radioactive wastes in temporary storage facilities the inevitable ageing of materials is a major concern, excerbated by nuclear radiation and complicated by economic factors. In addition, these facilities are vulnerable to terroristic attacks and damage from external accidents and natural disasters.

The radioactive wastes of uranium mining are dumped into the environment. Risks posed by dust and groundwater contaminated with the radioactive decay daughters of uranium and thorium are poorly, or not, investigated by the nuclear industry, but disadvantageously affect vast regions of territory around the mine sites, as well as local communities and workers.

Reprocessing plants are extremely polluting. All gaseous radionuclides from spent fuel are released into the air. A substantial part of the chemically mobile radionuclides are released into the sea, along with a significant fraction of the uranium, plutonium and other actinides from the spent fuel. Separation processes never go to completion (a consequence of the Second Law), so unavoidably a fraction of the radionuclides from the spent fuel end up in the waste streams of a reprocessing plant.

Redispersion by radioactive aerosols

Incineration of combustible 'low level' radioactive waste, a common practice within the nuclear industry, is a source of dispersion of radioactive materials. The scrubbers in rad waste incinerators are good, meaning they release only very fine particulate matter, but that includes PM2.5 which has now been declared the leading killer in the world, in part because it is the least likely to be expelled from the lungs.
Another important source of dispersion of radionuclides are forest fires. Even under normal conditions forest and wild fires happen annually in several highly contaminated areas- including the nuclear test zones in the USA, and around the Chernobyl exclusion zone and Russia's abandoned nuclear sites which has caused contaminated smoke to permeate some of Russia's most populated cities. Forest fires revolatilize radioactive waste that has bioaccumulated in tree and plant life reintroducing it into the biosphere as an inhalation danger.

Another source of radioactive and non-radioactive toxic aerosols are the mill tailings (waste dumps) of the uranium mines. The mill tailings are the waste stream of the physical and chemical processes for extracting uranium from its ore. It consists of finely ground ore, mixed with chemicals, solvents and large volumes of water containing dissolved radioactive and non-radioactive toxic chemicals. The waste water seeps into the ground contaminating the groundwater and partly evaporates; the dissolved wastes remain in the mill tailings as fine powder. The mill tailings are abandoned after the mine gets depleted and turn dry, and the extremely hazardous radionuclides and toxic materials are blown away by the wind as dust and fine particulate matter over distances of thousands of kilometers in arid areas, for example in Australia, Namibia, and the USA, see the Sahara dust cloud in Figure 5.

Bio-accumulation and the food chain

The amounts of radioactive substances routinely discharged into the environment by one NPP in any given year may seem relatively insignificant; however, year after year the radionuclides released may regionally build up significant concentrations in groundwater and soil. Moreover a number of long-lived radionuclides bioaccumulate in the food chain to high concentrations, even in a medium with very low concentrations of radionuclides (e.g. seawater). An example is the bioaccumulation of technetium-99 in seaweed [DECC 2009]. Another example is the accumulation of cesium-137 in mushrooms and wild boar. In Southern Germany the radioactive content of these foodstuffs still poses a health threat, even 25 years after the Chernobyl disaster [Rosen 2013].

Accumulation of radionuclides into the food chain greatly amplifies the health risks posed by routine or accidental discharges of radionuclides.

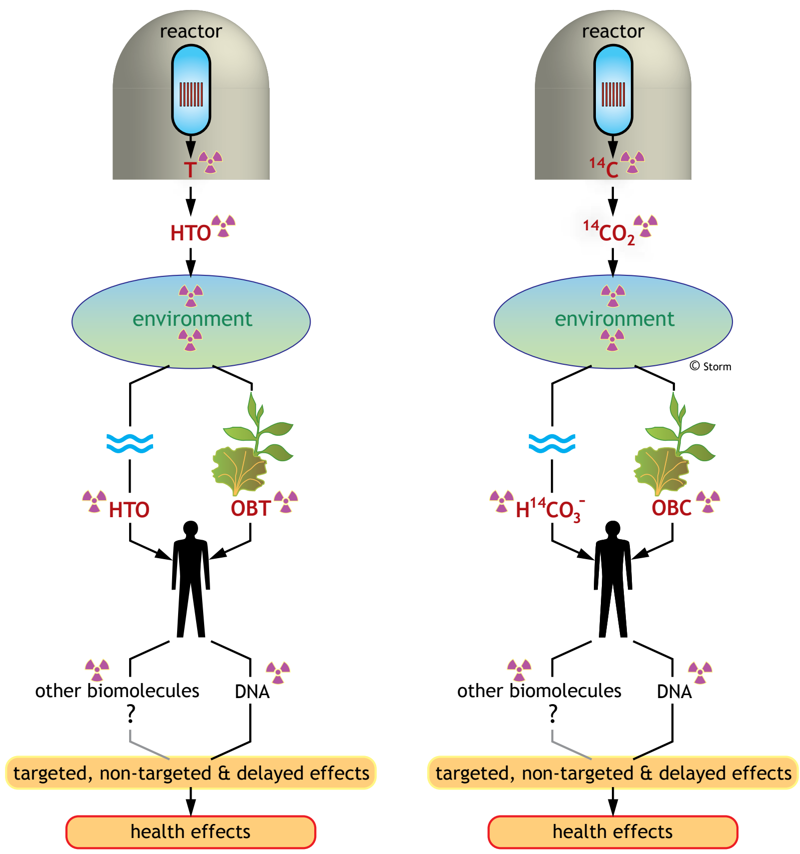

Figure 6

Pathways of tritium and carbon-14 into the human metabolism. Both radionuclides are routinely released into the environment by operating nuclear power plants. The pathways are similar, OBT = organically bound tritium, OBC = organically bound carbon-14. It is generally assumed that damage to DNA molecules cause detrimental health effects. Cell damage is not limited to the cells directly hit by radiation, due to the bystander effect. It is not known if radiation damage to other biomolecules could also cause detrimental health effects. See also [AGIR 2007] and [Fairlie 2008].

Important examples of radionuclides entering the food chain and drinking water are tritium (symbol ^{3}H, H-3 or T) and carbon-14 (symbol ^{14}C or C-14). These radionuclides are biochemically indistinguishable from their non-radioactive isotopes, normal hydrogen H, and normal carbon (mainly ^{12}C). Carbon and hydrogen are two of the six primary building blocks (C, H, O, N, S, P) of proteins and DNA. An aggravating factor is that both radionuclides are always discharged simultaneously. Some fission and activation products, including tritium and carbon-14, generated in a nuclear reactor are released into the environment by all normally operating nuclear power plants and the interim storage facilities of spent fuel. Tritium reaches the environment as tritiated water HTO, carbon-14 is mainly discharged as radioactive CO_2, that dissolves in rain water as hydrogen carbonate ions and so enters groundwater and the food chain

According to the classical dose-risk paradigm these discharges would have negligible public health effects, for tritium and carbon-14 do not emit gamma radiation, only weak beta rays, and for that reason some unrestricted discharge of both radionuclides has been and still is permitted. The assumption that these radioisotopes are harmless turns out to be inaccurate in view of the evidence of epidemiological studies [KiKK 2007] and [GeoCap 2012]. In addition this assumption ignores the biochemical behaviour of the two nuclides, and the non-targeted and delayed health effects, discussed in Chapter 3.

Radioactive waste management: current practices

The only way to minimise the exposure of the public to human-made radioactivity via insidious pathways and as a result of large-scale disasters is to immobilise the radioactive waste physically and to isolate it from the biosphere. The best solution is to dispose of all radioactive waste in large repositories deep in geologically stable formations, as soon as possible.

To deal with the global inventory of spent fuel at the current rate of generation about every three years a new large deep geological repository would have to be opened, comprised of a hundred kilometers of galleries with cavities to store the heat generating spent fuel canisters. To dispose of the existing inventory of spent fuel 10-15 of such deep geologic repositories might be required.
Safe storage of the other radioactive wastes requires construction of a different type of deep geologic repository, comprised of large caverns to store the containers with the operational and dismantling waste.
At the time of writing (2016) not a single geologic repository in the world was operational.

Spent fuel is stored in interim storage facilities: cooling pools and dry casks. After removal from the nuclear reactor the high residual heat generation of the spent fuel prevents reprocessing or direct storage in a geologic repository: it has to be cooled for many years before further handling is feasible. A small portion of the globally generated spent fuel has been reprocessed. All reprocessing waste, containing the bulk of the radioactive contents of spent fuel, is still stored in temporary facilities. By far the largest part of the globally generated spent fuel (hundreds of thousands metric tonnes) are still stored in interim storage facilities.

Shallow burial of operational and dismantling waste is being practised to save costs. For the foreseeable future the waste containers will continue leaking at an increasing rate, due to the inevitable processes of degradation. Risk of disturbing the disposal sites by human action, unwittingly or intentionally, grows with time. Knowledge about the contents of the containers at the disposal site likely will get lost. Experiences in the past prove this knowledge can be lost within a decade. Soil and groundwater will be irreversibly contaminated with many kinds of radionuclides, posing high health risks in the long run.

In the past large volumes of radioactive waste, including ship reactors, have been dumped at sea. Illegal dumping of radioactive waste at sea is still occurring.

The nuclear industry promotes two technological concepts as a reduction of the nuclear waste problem to ‘easy to manage’ proportions: vitrification of high-level radioactive waste and partitioning & transmutation of the long-lived radionuclides in high-level waste. Both concepts turn out to be based on fallacies: the waste problem would be worsened by their implementation. The main basis of the fallacies is ignorance of one of the most basic laws of nature, the Second Law of thermodynamics.

Accumulation of human-made radioactivity in the environment

As a result of radioactive discharges by nuclear power plants, reprocessing plants and other nuclear facilities, decade after decade, accumulation of human-made radionuclides in the environment occurs. Groundwater, rivers, lakes, soil and sea become increasingly contaminated by various kinds of radionuclides, including dangerous biochemically active nuclides that are not or hardly detectable with common radiation counters. Due to this accumulation the background radioactivity increases steadily with time. Comparison of exposure to radiation in a contaminated area with background radiation, "the exposure is only slightly higher than the background", and so suggesting that level is harmless, may evoke a false idea of the real health hazards.

Worrisome are the continuous discharges of krypton-85, a major fission product, into the air by nuclear power plants and reprocessing plants. Due to its relatively long half-life (10.7 years) this radioactive noble gas builds up in the atmosphere. As a result of human nuclear activities the inventory of Kr-85 in the atmosphere has risen by a factor of 10 million and this quantity shows a rising trend [Ahlswede et al. 2012], [Seneca 2015]. Although krypton is not a greenhouse gas in itself the presence of krypton-85 in the atmosphere gives rise to unforeseeable effects for weather and climate. Kr-85 is a beta emitter and is capable of ionizing the atmosphere, leading to the formation of ozone in the troposphere. Tropospheric ozone is a greenhouse gas, it damages plants, it causes smog and health problems.

According to [WMO 2000]:

> "The present background concentrations of ^{85}Kr in the atmosphere are about 1 Bq/m^3 and are doubling every 20 years. At this level, ^{85}Kr is not dangerous for human beings, but the air ionization caused by ^{85}Kr decay will affect atmospheric electric properties. If ^{85}Kr continues to increase, changes in such atmospheric processes and properties as atmospheric electric conductivity, ion current, the Earth's magnetic field, formation of cloud condensation nuclei and aerosols, and frequency of lightning may result and thus disturb the Earth's heat balance and precipitation patterns."

Orphan sources

Lost or uncontrolled sources ('orphan sources') are a major subject of concern to the metal recycling industry and also to the general public in terms of potential economic loss or public health impact.
Radioactive scrap metal or devices containing sealed radioactive sources are frequently found in construction and demolition debris, especially from industrial facilities; the frequency increases each year [NCRP-141 2002]. Gamma-emitting nuclides, such as ^{137}Cs, ^{60}Co and ^{241}Am are those most commonly detected. The nuclides are detected in the off-gas, slag and/or furnace dust of steel mills. Inadvertent meltings have also occurred at mills making metal products from recycled aluminium, carbon, copper, nickel, lead, zinc and gold. Sometimes sources containing nuclides such as ^{3}H, ^{90}Sr or ^{85}Kr are found by spotting warning labels or signs on scrapped equipment.

International trade in recycled metals and finished products made from recycled metals is complicating the controllability of radioactive scrap metals. Not all countries are equally meticulous in their regulations and control.
Volatile beta-emiters, such as ^{3}H and ^{14}C (as CO_2), may escape detection completely and are likely discharged from the mills into the environment undetected. What is known about other hard-to-detect radionuclides?

MOX fuel and nuclear terrorism

MOX is the acronym of Mixed OXide fuel, nuclear fuel with plutonium instead of U-235. MOX fuel is relatively little radioactive and can be handled without specialized equipment. A terrorist group would have not too much difficulty in making a crude atomic bomb from MOX fuel. Separating uranium dioxide and plutonium dioxide from MOX fuel can be done using straightforward chemistry. Converting the plutonium dioxide into plutonium metal, and assembling the metal together with conventional explosives to produce a crude nuclear explosive does not require materials from special suppliers. The information required to carry out these operations is available in the open literature [Barnaby 2005a], [Barnaby 2005b]. Technology needed to make nuclear bombs from fissile material is available outside of the established nuclear-armed countries and in the open literature, as proven in 'Nth Country Experiment' [Frank 1967], [Schneider 2007].
The authors of [MIT 2003] considered the proliferation and safety risks of reprocessing and the use of mixed-oxide (MOX) fuel unjustified. But there are also economic reasons not to recycle in their view.
Studies by the Oxford Research Group show that MOX fuel poses a large and underrated terrorist risk [Barnaby & Kemp 2007]. The 6 kg of plutonium contained in the Nagasaki bomb would fit in a soft drink can.

Nuclear weapons can be made from reactor-grade plutonium, although those made using weapons-grade plutonium may be more effective. The USA and UK exploded devices based on reactor-grade plutonium in 1956 and in the 1960s. A good nuclear weapons designer could construct a nuclear weapon from 4-5 kg of reactor-grade plutonium. Less reliability or a less predictable explosive yield than a military weapon would not be a problem for a terrorist group planning an attack in the center of a large town. This is the reason why so many scientists all over the world are strongly opposing the reprocessing of spent fuel and the use of MOX fuel in civilian reactors.

Severe nuclear accidents

In addition to the permitted and unplanned radioactive discharges large-scale accidents are possible, involving dispersion of massive amounts of radioactivity (100s to 1000s of nuclear bomb equivalents) within a short time period over vast inhabitated areas, affecting many millions of people. Radionuclides discharged in this kind of events are measurable worldwide. Potential sources of Chernobyl-like accidents are:

- nuclear reactors; actually happened at Chernobyl and Fukushima
- interim storage facilities of spent fuel, cooling pools; actually happened at Fukushima
- reprocessing plants; actually happened at Mayak in the former Soviet Union.

Nuclear facilities are vulnerable to terroristic attacks, for example by suicide bombers, that might initiate severe accidents. Severe accidents could also be initiated by hostile actions in an armed conflict anywhere in the world. The consequences of an accident like the Chernobyl and Fukushima disasters do not stop at the national borders. The spatial extent of the consequences of these disasters becomes evident by the dispersion maps of radionuclides in Figures 7 and 8. Only easily detectable radionuclides, such as cesium-137, are monitored and charted. During the disasters dozens of different radionuclides are dispersed, each with their unique chemical and physical properties, so the dispersion patterns of the released radionuclides may be vastly different from that of cesium-137.

Severe accidents may also go on slowly and insidiously, when spent fuel or reprocessing waste get dispersed during prolonged periods as a result of unnoticed leaks, without meltdown and/or explosions. The amounts of dispersed radioactivity could be massive and the contaminated area could be vast. The affected areas could become inhabitable because of heavy contamination of soil, groundwater, rivers, lakes and/or coastal seas.

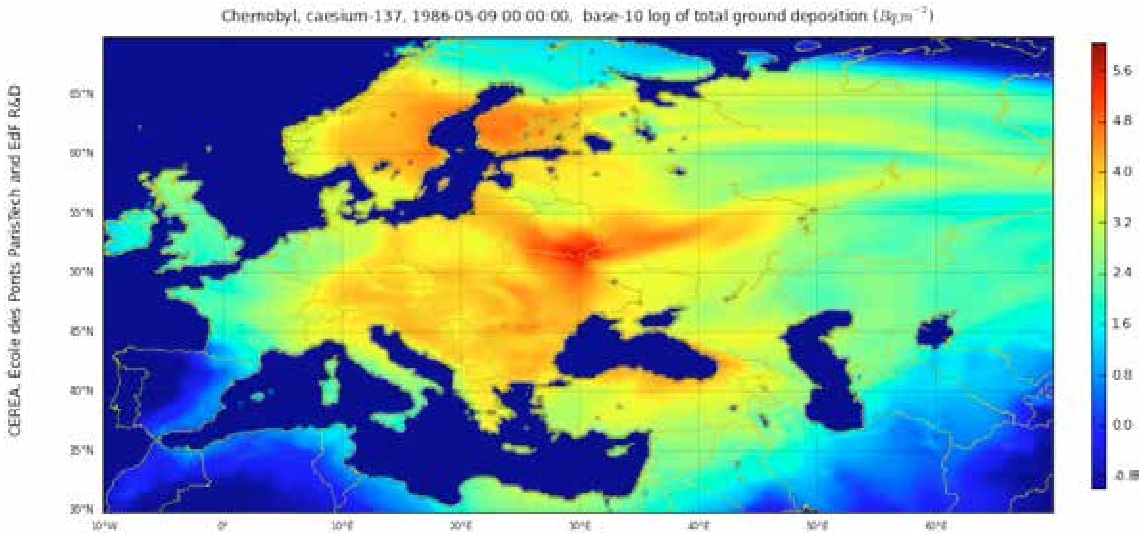

Figure 7

Map of the cumulative ground deposition of Cs-137 (Bq/m^2) on May 9, 1986 after the Chernobyl disaster. Note that the color scale at right gives the $^{10}\log$ values of the surface activity; for example the number 4.8 on the scale corresponds with a surface activity of $10^{4.8}$ = 63 kBq/m^2. Souce: CEREA 2013.

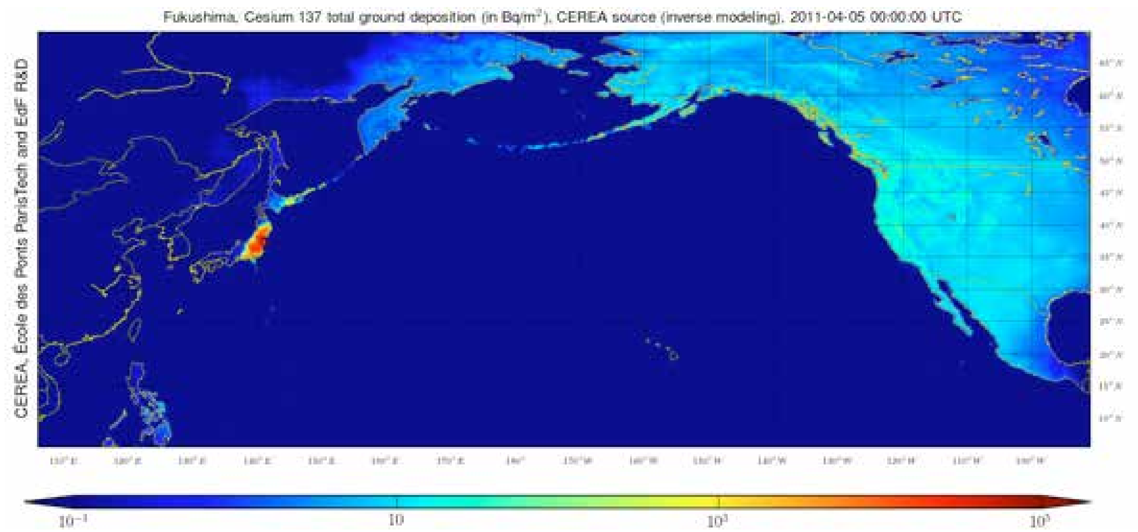

Figure 8

Map of the cumulative ground deposition of Cs-137 (Bq/m^2) on April 6, 2011 after the Fukushima disaster. Note that the color scale at right gives the $^{10}\log$ values of the surface activity; for example the numer 4.8 on the scale corresponds with a surface activity of $10^{4.8}$ = 63 kBq/m^2. Souce: CEREA 2013.

During the Fukushima disaster the main part of the radioactive contents of the melted down reactors are flushed (and are still being flushed) into the sea. Soluble radionuclides will disperse over large distances, little soluble radionuclides may end up in the sediments within much shorter distances. Many radionuclides may enter the food chain, the consequences are largely unknown. Many sea organisms tend to accumulate some radionuclides to high levels, even if their concentrations is seawater are very low.

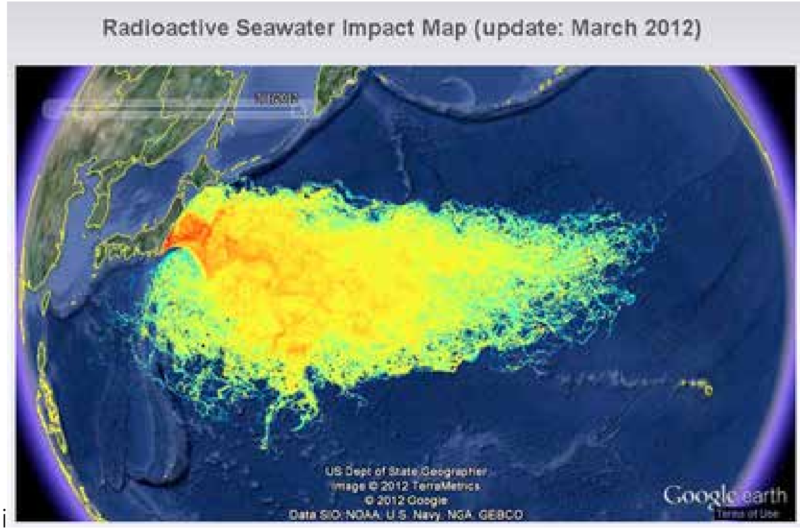

Figure 9

Radioactive seawater impact from Fukushima Daiichi. Image by TerraMetrics (2012) for US Department of State, Office of Geographer, using data from SIO (Scripps Institution of Oceanography), NOAA (National Oceanic and Atmosheric Administration), US Navy, NGA (National Geospatial-Intelligence Agency) and GEBCO (General Bathymetric Chart of the Oceans). The original publication could not be found on the web for free, but the image can be downloaded from various websites.

‘Preventable’ accidents

The official Japanese investigators called the Fukushima disaster a ‘man-made accident’ and a ‘preventable accident’ [NAIIC 2012a]. Obviously all accidents involving man-made objects and technical installations are man-made. At issue is the question: are ‘man-made’ accidents always preventable? A particular accident may seem preventable, for in principle many failure modes are preventable. However, the occurrence of ‘man-made’ accidents in general is not preventable. Accidents will happen, we just cannot predict where, when or which failure mode will occur.

Chairman Kiyoshi Kurokawa of the official commission that investigated the Fukushima disaster seems to endorse this viewpoint in his Preface to the final report [NAIIC 2012b]:

> The parties involved in this accident had forgotten some fundamental principles: “accidents will occur,” “machinery will break down,” and “humans will err.” They minimized the possibility of accidents to the point of denying it, and in doing so they lost their humility in the face of reality.

Are qualifications like ‘man-made’ and ‘preventable’ suggesting that nuclear power in itself is safe and that accidents like the Fukushima disaster could be prevented by writing better regulations?

3 Health effects of radioactivity

Interaction of nuclear radiation with living matter

Nuclear radiation is often called *ionizing radiation*, because it strongly interacts with matter forming ions. Ionizing radiation is harmful to living organisms, because it destroys or modifies biomolecules, such as DNA. Alpha radiation can be blocked by thick paper and beta radiation by aluminum foil, so these rays may seem not very harmful to man. However radionuclides radiating alpha or beta rays inside the human body are extremely dangerous, because the living cells are not protected by skin or clothing. The energy of the alpha or beta rays are given off within a short range and causes a large number of damaged biomolecules inside living cells. For example a dose of less than a microgram of the alpha-emitter polonium-210 in the human body is lethal.
A complicating factor is that alpha and beta radiation are hardly or not detectable by most hand-held counters. Radionuclides that emit weak or no gamma rays are invisible to these detectors. A number of biologically very active radionuclides fall within this category, such as tritium, carbon-14, iodine-129 and a number of actinides. These radionuclides can be detected only by special equipment.

Not until the early 1970s was it discovered that protacted radiation exposures from long-lived radionuclides accumulating in the body is much greater than from the same total dose received in a short X-ray exposure. A number of radionuclides have been investigated to some extent, while other nuclides (among them carbon-14) have gone practically uninvestigated.

Accumulation in specific organs

Several radionuclides have a specific biological behaviour and tend to accumulate in a specific organ or tissue. For example: technetium-99 and radio-iodine seek out the thyroid gland, together with the non-radioactive sister atoms, and damage the production of key growth hormones and cause thyroid cancer. Strontium-90, ruthenium-106 and plutonium isotopes tend to accumulate in bones, where they irradiate the bone marrow, causing leukemia in newly forming red blood cells as well as damage to crucial white cells of the immune system that fight cancer cells and bacteria. Cesium-137 collects in soft tissue organs, such as the breasts and reproductive organs of females and males, leading to various types of cancer in the individuals and their childern as well as in later generations [Sternglass 2009].
In such cases, the radioactivity is not evenly distributed in the body and doubling of the radioactivity of the body as a whole, means a sharp local, or organ/site specific increase in radiation. The chemical properties of an element are not affected by the radioactivity of its atoms. As a consequence the chemical behaviour of radionuclides in the human body is identical to that of their non-radioactive isotopes, but their biomedical properties are not.

Biochemical reactions of radioactive atoms

When a radioactive atom decays inside a human body an atom of another element comes into being. This change of identity will cause a chemical reaction. The nuclear radiation from the decay will generate large numbers of secondary ions, each of which will cause also chemical reactions. Chemical bonds will be broken and new ones will be formed. Existing molecules can be destroyed and new molecules can be formed. Several factors are important in judging the biological hazards of radioactive substances in the human body, such as:

- biochemical behaviour of the radioisotope itself and of its decay products

- biochemical reactions initiated by the ionizing radiation of the radioactive decay, via primary and secondary ions
- biochemical reactions initiated by the energy transfer of the decay (recoil) and of the secondary electrons.

Deterministic health effects

The nuclear industry and related institutions discern two categories of health consequences of exposure to radiation: deterministic and stochastic effects. This distinction is coupled exclusively to the radiation dose a person contracted. Deterministic effects occur at very high doses within a short period and are due to cell killing on a massive scale. The effects, often called Acute Radiation Syndrome (ARS) or radiation sickness, become evident within a time period of minutes to weeks, depending on the contracted dose. Deterministic effects may occur in case of exposure to nuclear explosions, to unshielded spent nuclear fuel, or other highly radioactive materials, for example in case of large nuclear accidents.
Attribution of deterministic effects to radiation exposure requires, according to [UNSCEAR 2008b]:

- at least a suspicion of an exposure above a threshold, usually of a gray or more,
- observation of a specific set of clinical or laboratory findings in a particular time sequence.

Stochastic health effects

Stochastic effects (also called probabilistic effects) occur at random. The classical radiobiology assumes a linear relationship between radiation dose and effects. If a large number of individuals receive the same dose, one can predict the number of individuals who will develop a health effect, but which effect and which individual is not predictable. With regard to stochastic effects there is no threshold of the received dose below which effects could not occur, apart from zero dose.

Attribution of stochastic health effects to exposure to radiation and contamination by radionuclides is problematic. Usually it is not possible to prove unambiguously the relationship between a once contracted dose of radiation and carcinogenic, mutagenic or teratogenic effects occurring many years later, because a number of factors and uncertainties are involved, such as:

- long latency periods of the observable health effects
- stochastic character of the biological effects
- many effects are not specific to exposure to radiation or radioactive substances and can be induced also by other, non-radioactive causes
- age, gender of the individual
- uncertainties of the actually received dose
- has a particular individual been exposed to low doses during a long period or higher doses during a shorter period
- which nuclides are involved
- basic biological unknowns.

In addition the kind of exposure is important: was the individual exposed to radiation from nuclides external to the body, or internally from nuclides within the body? In which chemical form did the nuclides enter the body: by inhalation of dust and gas, or by ingestion via food and drinking water? In which chemical state did the radionuclide enter the body: as a free element, as an inorganic species or as an organically bound species? This issue is further complicated in case of chronic exposure to low doses of a number of radionuclides simultaneously.
Biochemical properties of any radionuclide inside a living organism are identical to the biochemical

properties of its non-radioactive isotopes (atoms of the same element with a stable nucleus), so they can be incorporated in biomolecules that are vital for the health of the organism. Even weak alpha and beta radiation emanating from the incorporated radionuclides can cause serious damage to biomolecules, e.g. DNA, in living cells, which in turn may cause detrimental effects in the organism.

Non-targeted and delayed effects

Relatively recent studies proved the existence of 'non-targeted' and 'delayed' radiation effects. These effects had probably been observed in earlier studies but had gone unrecognised as they fell outside the then accepted paradigm of radiation effects. Non-targeted effects, which arise as a result of damage/changes to unknown areas in the cell, are termed 'non-targeted' because they mainly do not cause damage/changes to DNA or chromosomes, heretofore believed to be the main site for radiation's lesions. Non-targeted effects include, according to [Fairlie 2010a]:

- genomic instability (effects occurring up to 20-30 generations later in the progeny of an irradiated cell),
- bystander effects (effects in unirradiated cells situated close to irradiated cells),
- clastogenic effects (causing chromosome disruption or breakages in blood plasma that result in chromosome damage in non-irradiated cells), and
- heritable effects of parental irradiation that occur in succeeding generations.

The classical explanation for radiation's effects was that they were mostly caused by structural DNA damage (i.e.single and double-strand DNA breaks) which resulted in mutations in the cell's genetic information that, without repair or elimination, would end eventually in cancers. This is the Target theory of radiation effects, the target being specific sequences in DNA and chromosomes.
The dose-response curve of non-targeted effects is often not linear, with substantial increases at very low doses followed by a levelling off at higher doses. Presently there is no mechanical explanation for how the non-targeted effects actually occur [Fairlie 2010a]. The target for radiation damage is greater than the initial tissue volume irradiated [Morgan & Sowa 2005]. A historical overview is given, among others, by [Mothersill & Seymour 2006].
The observed phenomena pose many fundamental questions to be answered and will result in a paradigm shift in the understanding of radiation biology.

Observed health effects

The consequences of a nuclear accident implying releases of radioactive materials into the environment become observable only after years, due to long incubation periods. In the regions contaminated with radionuclides after the Chernobyl disaster a greatly increased incidence of a many different malignant and non-malignant diseases and disorders were observed during the first 25 years after the disaster [IPPNW 2011], such as:

- multimorbity classified as radiation-induced premature senescence
- cancers and leukaemia
- thyroid cancer and other thyroid diseases
- damage to nervous system, mental disorders
- heart and circulatory diseases
- infant mortality, stillbirths, low birth-weight
- congenital malformations
- endocrinal and metabolic illnesses
- diabetes
- miscarriages and pregnancy terminations

- genetic damage, hereditary disorders and diseases
- teratogenic damage, such as: anencephaly, open spine, cleft lip/palette, polydactylia, muscular atrophy of limbs, Down's syndrome.
- chromosomal damage
- radiation-induced cataracts
- vascular vegetative dystony (the "new Chernobyl syndrome")

In addition persistent ill health effects are observed in childern after the Chernobyl disaster [Fairlie 2016a], such as:

– impaired lung function, increased breathing difficulties
– decreased blood count
– increased immunoglobin factors
– increased anaemias and colds.

A major study originating from the affected regions [Yablokov et al. 2009], based on 5000 scientific papers published in Russia, Belarus and Ukraine, cites a death toll of the Chernobyl disaster worldwide of 985000 people. Independent scientists in the USA and Canada estimated the global deathtoll, including future cases, at 0.9 – 1.8 million people [Yaboklov 2011]. According to Yablovkov the largest percentage of excess deaths resulting from Chernobyl are caused by cardio-vascular diseases, not by cancer.
The IAEA and UNSCEAR (and also the WHO) do not recognize non-cancer diseases as being stochastic effects due to radiation, and do not refer to investigations of non-cancer diseases. Only thyroid cancer is mentioned as a radiogenic stochastic effect, because this type of cancer is normally very rare among childern and the incubation period is relatively short.

An independent epidemiological study of the relationship between nuclear power and health risks is the German study [KiKK 2007]. With regard to the incidence of cancers with childern before their 5th birthday, living within a distance of 5 km from a nuclear power plant, the KiKK study found a significant increased incidence of childhood leukemias and childhood solid cancers, and a strong association with proximity to a nuclear reactor. The results of the [KiKK 2007] study are confirmed by the French epidemiological investigation [Geocap 2012], [Koerblein & Fairlie 2012]. These results cannot be explained by the currently used radiological models [Fairlie 2014].

Chernobyl and Europe

Dispersion of radioactive materials from a nuclear disaster elsewhere in the world does not stop at our borders. According to [Fairlie 2016a] half of Chernobyl's fallout has been deposited on western Europe; 42% of western Europe is seriously contaminated. Increased thyroid cancers are observed in Austria and other western European countries particularly Slovakia, Slovenia and Moldova. Raised thyroid cancer levels were observed as far away as Northern England [TORCH 2016].

4 Limitations of radiological models

Reliance on models

Widely different viewpoints exist, not only regarding health hazards of radioactive contamination near of nuclear installations under normally operating conditions, but also on the effects of large-scale exposure to radiation and radioactive materials as a result from nuclear disasters such as Chernobyl and Fukushima. The controversies turn out to be the result of different approaches to looking at this complex matter: the nuclear industry relies on theoretical physical models for its assessments of health hazards, while physicians and the general public look at the empirical evidence. In addition, the economic and financial interests of the nuclear industry may play a dominant role in the health hazard assessments.

Inherent limitations of any physical model

Like any scientific model the radiological models have inherent limitations, because a model is by definition a simplication of the reality and is based on a number of axioms and assumptions. As a result of the simplification of the reality a model is only valid within specific system boundaries and has a limited application range. The wider the system boundaries of a model, the more complicated its structure. How are the radiological system boundaries defined? In addition to its inherent limitations a model generally also has limitations originating from the choice of the input data.
From a scientific/mathematical viewpoint the radiological models should be based on unvaryingly verifiably accurate parameters and variables under specified physical conditions. The standards based on the radiological models turn out to be flexible under economic pressure as proven, for example, by the relaxation of authorized radioactivity standards for drinking water in the USA, necessary to keep the aging nuclear power plants economically operable, and the relaxation of exposure standards in Japan after the Fukushima disaster.

Limited scope of the radiological models

The Committee [UNSCEAR 2010] stated:

> "the single most informative set of data on whole-body radiation exposure comes from studies of the survivors of the atomic bombings in Japan in 1945. The atomic bombing exposures were predominantly high-dose-rate gamma radiation with a small contribution of neutrons."

For more information on UNSCEAR, two other international nuclear organizations (IAEA, ICRP) and WHO see Chapter 5.

In his analysis of the World Health Organization report [WHO 2013a] on the Fukushima disaster [Rosen 2013] discusses eight objections to that report, one of them reads:

> "The authors explain this procedure, by basing their assumptions on the Lifetime Span Studies (LSS), performed on the survivors of the nuclear bombings of Hiroshima and Nagasaki – studies that were only started in 1950, five years after the events occurred. How studies on the survivors of the mostly external radioactive exposure of the nuclear bombs, without any scientific knowledge from the first five years, including no records of miscarriages, neonatal mortality or congenital defects, could be transferred to a scenario where children and fetuses were exposed to mostly internal radioactivity after a nuclear catastrophe is not adequately addressed by the report's authors."

Which assumptions form the basis of the currently used radiological models? Which phenomena are included in the models and which are not?

What was the original purpose of these 60 years old models, developed in a time only military nuclear facilities were in operation? These studies started about five years after the bombings, so the deaths during these first five years are not counted [CERRIE 2004]. More on questionable aspects of the way of constructing the radiological model are discussed by [Hoffmann 2016].
Was the purpose to estimate the acute radiological risks for military personel in wartime, during the 1940s and 1950s, the Cold War, or to estimate the health risks for millions of people in the 21st century posed by chronic exposure to a number of radionuclides from failing civilian nuclear power stations? The global nuclear generating capacity grew from tens of megawatts in the 1950s to hundreds of gigawatts today, a factor of 10 000.

The methodology and scope of these studies do not comply with present scientific views and insights, based on the vast amounts of emprirical data available. The epidemiological studies [KiKK 2007] and [Geocap 2012] proved that the existing exposure and health risk models are unable to explain the empirical observations of these studies, so the models should be revised.
During the disaster of Fukushima amounts of radioactivity equivalent to thousands of Hiroshima bombs have been discharged into the environment, and are still being discharged.

Exposure to radioactivity implies more than radiation alone

The radiological models used by the nuclear industry are based on the effects of gamma- and X-ray radiation from sources *outside* the human body. Probably for that reason the nuclear industry is speaking invariably about effects due to exposure to *radiation* and not about effects due to contamination by *radioactive materials*.
Biomedical behaviour is not included in the radiological models, let alone the synergistic behaviour of a number of radionuclides of different chemical elements simultaneously. In the case of large nuclear accidents dozens of different types of radionuclides are released into the human environment and consequently residents become contaminated not just by one type of radionuclide but with a number of different radionuclides. Uncertainties are exacerbated by the fact that many dangerous radionuclides are not detectable by means of hand-held radiation counters. Only a few are easily detectable, for example the strong gamma emitters iodine-131 and cesium-137. As illustrated by dispersion maps published after the Chernobyl disaster and Fukushima disaster, the dispersion of the various radionuclides during a calamity may have different patterns. The extent of contamination by cesium-137 is far from a reliable measure for the extent of contamination by other radionuclides, due to their different physical and chemical properties. Consequently the extent of radioactive contamination is insufficiently known.

What are the effects if the exposure is chronic as a result of continuous intake (food, water), inhalation of gases, dust and fine particulate matter (PM) due to the burning of material contaminated by radionuclides for heat or cooking, or due to forest fires in contaminated areas over the course of many years? Or proximity to radioactive waste incinerators, which release, by definition, very fine particulate matter?

How reliable are estimations based on models?

- Measurement of the gamma radiation from one or two radionuclides tells only a part of the potential exposure to radiation from a number of radionuclides.
- Exposure to radiation tells only a part of the potential contamination by radioactive materials, internal as well as external, as pointed out above.
- Health consequences of radioactive contamination by one kind of radionuclide over a long term period are poorly understood, let alone contamination by a number of different radionuclides.
- Health consequences observed during the first few years after radioactive contamination tell only a minute part of the health consequences in the long run.

Linear No-Threshold model and radiation hormesis

In 2015 the US Nuclear Regulatory Commission (NRC) sought public comments on three petitions stating that the Linear No-Threshold (LNT) theory of radiation's effects was not a valid basis for setting radiation standards and that the hormesis model should be used instead. The NRC has received three petitions for rulemaking requesting that the NRC amend its "Standards for Protection Against Radiation" regulations.
The LNT model assumes that biological damage from radiation is linearly related to exposure and is always harmful. The hormesis model assumes that exposure to low radiation levels is beneficial and protects the human body against deleterious effects of high levels of radiation.

The radiation hormesis hypothesis seems to be based on limited model studies and on analogy with chemical hormesis. Chemical hormesis is the phenomenon that a chemical species is assumed to be non-toxic in very low doses, or even beneficial, and toxic in higher dosis. The analogy with the supposed chemical hormesis is highly questionable, because of the completely different biological mechanisms involved in the effects of chemical species and of radioactivity in the human body. There are no independent scientific studies known that support the radiation hormesis model. An increasing evidence exists that even background radiation is harmful. The scientific evidence for the LNT is plentiful, powerful and persuasive, according to [Fairlie 2015b].

The three petitions [Marcus 2015], [Miller 2015] and Doss et al. 2015] – the petitions of Miller and Doss are based on the petition of Marcus – did not provide a clear reason for why the studies supporting the LNT model are flawed in their view and why studies supporting the hormesis model are correct. On the contrary, Miller for example seems to limit its argumentation to depreciation in unscientific statements of other's work. Only the incidence of solid cancers were involved in the arguments, non-cancer diseases are not mentioned as radiogenic health effects. The petitions did not quantify the limits of what is called hormetic 'low' doses. Comparison with background radiation may introduce a serious bias in the models as explained in Chapter 2.
The petitions put forward economic arguments as a reason not to comply with the LNT model [Marcus 2015]:

> "The costs of complying with these LNT-based regulations are enormous. Prof. Dr. Gunnar Walinder has summed it up: 'The LNT is the greatest scientific scandal of the 20th century.'"

and fear for panic and radiophobia [Doss et al. 2015]:

> "One reason for the urgency of action on this petition is that any potential future accident involving release of radioactive materials in the USA would likely result in panic evacuation because of the LNT- model-based cancer fears and concerns, resulting in considerable casualties and economic damage such as have occurred in Fukushima. The recognition of a threshold dose by NRC would obviate the need for such panic evacuations, associated casualties, and economic harm."

The petition of [Marcus 2015] recommends:

1) Worker doses should remain at present levels, with allowance of up to 100 mSv (10 rem) effective dose per year if the doses are chronic.
2) ALARA should be removed entirely from the regulations, as it makes no sense to decrease radiation doses that are not only harmless but may be hormetic.
3) Public doses should be raised to worker doses, as these low doses may be hormetic. Why deprive the public of the benefits of low dose radiation?
4) End differential doses to pregnant women, embryos and fetuses, and children under 18 years of age.

Point 4 is in conflict with the results of the undisputed KiKK and GeoCap studies. Even medical use of radiation can be harmful according to [Hoffmann 2016].

5 Entanglement of interests

Nuclear complex

A nuclear power plant is part of an intricate network of industrial activities. In turn this technical system is part of a complex of interests, with miltary, political, economic, social, environmental and health aspects. By reason of the diversity of interests it is not simple for the public and policy makers to get a reliable overview of the nuclear energy system in all its aspects.
The first responsibility for protecting public health lies with the State [Baverstock 2016]. States are rarely independent of the nuclear energy producers. Private nuclear energy producers are unable to obtain insurance for the cost of accidents; therefore they are effectively insured by the taxpayer. This creates a conflict of interest that in practical situations leads to a trade-off between the protection of the public health and the protection of the economy.
Furthermore, information on civil nuclear power to the general public and policy makers is globally dominated by the International Atomic Energy Agency (IAEA).

Three international nuclear organizations

IAEA

The International Atomic Energy Agency (IAEA) is an international organization, established independently of the United Nations, through its own international treaty with the member states. The IAEA Statute entered into force on on 29 July 1957 ((www.iaea.org/About/statute). Total Membership: 159 states (as of February 2013). The Democratic People's Republic of Korea (DPRK), which joined the IAEA in 1974, withdrew its membership of the IAEA in 1994. (www.iaea.org/About/Policy/MemberStates/)
Official publications of the IAEA have to be approved by all its member states.
The IAEA has two mandates: one as *watchdog* to prevent malicious use of nuclear technology – a role primarily restricted to guarding against illegal nuclear weapons production and proliferation risk –, the other as *promotor* of nuclear power. These two mandates create a serious conflict of interest, thus the IAEA cannot be considered to be an independent scientific institute. The IAEA has been very successful in forging links to national bodies responsible for standards at the national level. It is increasingly difficult to find experts that have not been involved with the IAEA [Baverstock 2016].
Military and civil nuclear technology are basicly identical, just the military and civil applications may be different. In the past the IAEA did not obstruct the sale by IAEA members of sensitive nuclear technology to unreliable countries.

Two other international nuclear institutions, the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have strong connections with the IAEA.

ICRP

Originally the exposure recommendations of the ICRP, founded in 1928 and restructured in 1950, were designed for application in known radiation exposure situations: the planned use of radiation sources (X-ray and natural radioactive material) for medical, scientific and technical purposes.
The International Commission on Radiological Protection (ICRP) has more than 200 volunteer members from about 30 countries Future members are exclusively appointed by its present members. Its membership includes former staff of the IAEA and members of government advisory bodies. According to the ICRP

publication *1959 Decisions* (see www.icrp.org):

> 'The Commission has an official relationship with the World Health Organization and the International Atomic Energy Agency. There has been close co-operation with the United Nations Scientific Committee on the Effects of Atomic Radiation, ...'

The above mentioned issues are still by far the main preoccupation of the ICRP. Only a small number of the 140+ ICRP publications deal with exposures as a result of human-made radioactivity from nuclear power [ICRP 103 2007] and [ICRP 111 2009].
Further, the main task of the ICRP seems to be the formulation of a legal framework for authorities and politicians on how to cope with any *liability* which may arise from exposure of people to radiation and/or radioactive materials, not how to cope with human health harm from exposure itself, or prevention.
How is the word 'protection' in the name International Commission on Radiological Protection to be interpreted by the general public when after a nuclear accident the permissable level of radioactivity in food and drinking water is instantly raised by a factor of 10, 100 or even more, without any scientific argument or discussion, as happened after the Fukushima disaster?

UNSCEAR

The United Nations Scientific Committee on the Effects of Atomic Radiation was established 3 December 1955. The United Nations General Assembly has designated 27 States as members of the Scientific Committee. The mandate reads [UNSCEAR 2010]:

> "to undertake broad assessments of the sources of ionizing radiation and its effects on human health and the environment."

UNSCEAR is supported mainly by those countries operating nuclear reactors and they provide the scientific expertise for the committee. There is, therefore a substantial conflict of interest in that States with a conflict of interest nominate members to the committee [Baverstock 2016].
The work of UNSCEAR seems to be focused on exposure to external radiation chiefly from natural sources. The impression is given that UNSCEAR (and also ICRP) cares more about radiation from natural sources than from human-made sources.
Is natural radioactivity more dangerous than human-made radioactivity?
And, if we have to worry about natural radioactivity, why not about radioactivity from nuclear power plants? The amounts of human-made radioactivity present in the human environment are billions of times greater than the naturally occurring amounts and involve dozens of different and hazardous radionuclides not occurring in nature. Large amounts of those human-made radionuclides are being dispersed into the environment by intended and unintended discharges, and can easily enter the food chain and drinking water.
Recent statements [UNSCEAR 2010] prove that UNSCEAR still sticks to 60 year old databases, based on studies of the survivors of the atomic bombings in Japan in 1945; this issue is discussed in Chapter 4.

Role of the WHO

The Constitution of the World Health Organization entered into force on 7 April 1948. In the following years several amendments were adopted and incorporated in the present text, and entered into force in 1977, 1984, 1994 and 2005 [WHO 2009]. Article 1 of Chapter I - Objective reads:

> "The objective of the World Health Organization (hereinafter called the Organization) shall be the attainment by all peoples of the highest possible level of health."

According to an agreement between the International Atomic Energy Agency and the World Health

Organization (UN Res. WHA12-40, 28 May 1959) the WHO cannot operate independently of the IAEA on health effects of radiation. Its independence is compromised by its lack of expertise on radiation and nuclear health issues; reversely, lack of expertise might result from its lack of independence.
Although the WHO is an independent UN organization, its reports on health effects of nuclear power are subject to IAEA's approval and consequently reflect the view of the IAEA.

One voice

With respect to health hazards of radiation and radioactive materials originating from nuclear power, the IAEA, UNSCEAR and WHO are speaking with one voice, as is proved by the reports from these organizations on the disasters of Chernobyl and Fukushima. As a result of the authoritive global status of the IAEA, UNSCEAR and WHO governments all over the world receive exactly the same information concerning nuclear issues. Obviously this is a matter of one-sided information, exacerbated by the fact that the three organizations do not mention divergent views of scientifically well-underpinned studies from independent sources. These facts may hamper democratic decision processes concerning nuclear issues.

Re-evaluation?

The agreement between the IAEA and the WHO was established in a period dominated by the Cold War and threats of the use of nuclear weapons. The nuclear world in those years comprised solely military applications of nuclear technology; the first small civil nuclear power plants were just in the pipeline. Since the 1950s a massive expansion of civil nuclear power has taken place, an increase of scale by a factor 10000, while the military nuclear activities stayed at a constant level or even declined until recently.
Could anyone in the 1950s foresee this expansion?

The threat of atomic bombings may have declined since the 1950s. However, there is still a civil threat from within. The safety and health hazards originating from nuclear technology in this time, threatening hundreds of millions of people, are posed by the huge amounts of radioactivity (more than 11 million nuclear bomb equivalents) generated by hundreds of large nuclear power plants. These amounts of radioactivity are still present within the human environment and are growing day by day. Also growing day by day are the unplanned releases of radioactive materials into the environment The risks of severe accidents are growing with the amounts of radioactivity and with the number of nuclear power plants, exacerbated by the unavoidable and progressive deterioration of the materials containing the radioactive materials.
Apart from multigenerational human harm for millions of people nuclear accidents can cause massive economic damage. The disasters of Chernobyl and Fukushima affected many millions of people. The death toll of Chernobyl is estimated at about one million people. Both disasters individually are costing hundreds of billions of dollars, to be paid by the taxpayer.
How are the responsibilities and liabilities of the nuclear industry defined?

As a global health organization the WHO is assumed to assess *all* kinds of health hazards humankind is confronted with and to mitigate the potential harm and damage as much as possible, as follows from the objective of the WHO. Likely the WHO is the only global health organization able to counterbalance the views of globally operating interest groups, for instance the nuclear industry. The primary task of the WHO should not be to comply with the views of the IAEA, aimed at the interests of the nuclear industry, but to focus on its own Article 1 of Chapter 1, independently, see also http://independentwho.org/en/. With regard to this issue recommendations are formulated in [TORCH 2016].

Time for re-evaluation of the global position of the WHO?

At the European level

The International Agency for Research on Cancer (IARC) is conducting project Co-CHER for the European Commission (EC), which is a follow-up of the Agenda for Research on Chernobyl Health (ARCH). The EC apparently tried to evade the recommendation of the ARCH project and has insisted that Co-CHER was run under the auspices of/or at least with participation from the Multidisciplinary European LOw Dose Initiative (MELODI). This immediately threatens the independence of IARC: clearly the EC is not interested in independence [Baverstock 2016].

The EC conducts its radiological protection research under its energy programme, specifically the EURATOM treaty. The Commission's role is:

> "It shall be the task of the Community (EURATOM) to contribute to the raising of the standard of living in the Member States and to the development of relations with the other countries by creating the conditions necessary for the speedy establishment and growth of nuclear industries."

As things stand as present the European Commission has a conflict of interest and cannot be regarded as independent.

It is recommended to provide funds for independent investigations by IARC of cancer and non-cancer health effects resulting from radioactive contamination from Chernobyl [TORCH 2016].

6 Downplaying and denial of nuclear health effects

Long latency period of radiogenic health effects

Empirical quantification of the relationship between exposure to radioactivity and the (always detrimental) health effects is difficult. Diseases are seldom labeled with their cause so it is rarely possible to prove unambiguously the relationship between a once contracted dose of radioactivity on individual scale and carcinogenic, mutagenic and/or teratogenic effect, for several reasons:

- long latency periods: months to years or even decades
- stochastic character of the biological effects
- broad gamut of possible ill effects possible, most of them can also induced by non-nuclear causes
- basic biomedical unknowns
- lack of empirical data: lack of systematic epidemiological investigations

When a large number of people are exposed to a given low dose of radioactivity, it is not possible to predict which person will develop a health effect (or even more than one), nor which effect(s), nor its latency period. It may only be possible to predict what fraction of the group will develop a health effect.
The long time lag between exposure and observable health effects forces the medical sciences to employ special methods to assess the hazards of nuclear power. For example the heritable damage to egg cells in young women may only become evident after some 30 years. Gaining insight is possible by means of appropiate epidemiological investigations.

Denial
Apparently the nuclear industry takes the view that if the relation between exposure to radiation and a health effect in a particular person cannot directly be proved within a short time period, the cause of the observed disease must be non-nuclear. This attitude is not backed by any epidemiological proof. Only effects of exposure to extremely high doses of radiation which become observable within hours to days, called deterministic effects, are recognised as radiation induced health effects.

Epidemiological studies

Reliable investigation of the effects of radioactive contamination, that implies more than radiation alone as explained in Chapter 4, in the human environment needs the registration of incidence of ill effects over a long time span. By means of epidemiological studies an independent assessment of the consequences of exposure, especially chronic exposure, to radioactive materials is possible. Unfortunately such studies and record keeping remain undone.

Epidemiological studies are also needed to analyse the effects of permanent exposure to low doses of radionuclides via water and food in contaminated areas, not only after a large accident, but also near normally operating nuclear power plants and reprocessing plants. Such an investigation should be continued for many years, because of the long incubation periods of diseases caused by exposure to radionuclides.

Major independent epidemiological studies in Germany and France [KiKK 2007] and [GeoCap 2012] found a strong connection between the incidence of cancers in young childern and how close they lived to normally functioning nuclear power plants. The existing models of dose-effect relationships cannot explain the empirical results of these studies, so the models are inadequate. Nevertheless the nuclear industry ignores these studies and still sticks to outdated, biased radiological models. Publications of the World Nuclear Association (WNA) do not even mention the KiKK and GeoCap studies.

Fairlie [Fairlie 2016a] points out that care is required concerning the interpretation of epidemiological studies after the Chernobyl disaster because of:

- differing diagnostic criteria used
- insufficient/poorly matched control groups
- small numbers – low statistical power
- confounding factors and biases
- nil or poor dose estimates

In addition people move away, cases disappear. Political decisions are made not to do studies that might provide undesired results.

The reports of the IAEA, UNSCEAR and WHO on the disasters of Chernobyl and Fukushima do not mention epidemiological studies, nor the intention to perform such investigations in the future; even the word 'epidemiological' is extremely rare in these reports.
Why have the IAEA, UNSCEAR and WHO been allowed to systematically avoid disussion on epidemiological studies?
If it is possible to prove the relationship between consumption of red and processed meat and the incidence of cancer [IARC/WHO 2015], why should it be impossible to prove relationship between contamination with radioactive materials and health effects?

Report of the WHO on Fukushima

In its news release of 28 February 2013 the World Health Organization [WHO 2013b] states:

> A comprehensive assessment by international experts on the health risks associated with the Fukushima Daiichi nuclear power plant (NPP) disaster in Japan has concluded that, for the general population inside and outside of Japan, the predicted risks are low and no observable increases in cancer rates above baseline rates are anticipated.

and:

> ... the radiation doses from the damaged nuclear power plant are not expected to cause an increase in the incidence of miscarriages, stillbirths and other physical and mental conditions that can affect babies born after the accident.

and:

> A breakdown of data, ..., does show a higher cancer risk for those located in the most contaminated parts. Outside these parts - even in locations inside Fukushima Prefecture - no observable increases in cancer incidence are expected.

and:

> "The WHO report underlines the need for long-term health monitoring of those who are at high risk, along with the provision of necessary medical follow-up and support services,"

With regard to the report this news release is based on [WHO 2013a], the WHO states:

> This is the first-ever analysis of the global health effects due to radiation exposure after the Fukushima NPP accident and is the result of a two-year WHO-led process of analysis of estimated doses and their potential health implications. The independent scientific experts came from the fields of radiation risk modelling, epidemiology, dosimetry, radiation effects and public health.

Critical analysis of the WHO report on Fukushima

According to the IPPNW study [Rosen 2013 [Q561] the assessment of the WHO *Health risk assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami based on a preliminary dose estimation* [WHO 2013a] is based on preliminary dose estimations, published by the WHO in May 2012, which were severely criticized by the German Section of IPPNW, independent researchers and Japanese civil organizations. In his analysis Rosen discusses the eight main objections to the current WHO report and shows why it should not be considered a neutral scientific assessment of the actual health risks of the affected population, nor a valid basis for future decisions and recommendations. Summarised the eight points are:

- The WHO report is based on faulty assumptions
- The report ignores the health risks for people outside of Fukushima.
- Continued radioactive emissions were not included in the assessment.
- The report ignores the increased radiosensitivity of the unborn child.
- Recent clinical findings were not taken into considerations.
- Non-cancer diseases are not included in the health risk calculations.
- The report relies solely on TEPCO's own data to assess workers' health risk.
- The authors' neutrality has to be doubted.

Conclusion

As doctors and scientists, we are fully aware of the difficulties in calculating comprehensive health risks of a large catastrophe for such a large population and know of the problems that naturally arise in such an attempt.

- It is extremely important to base calculations such as these on reliable and valid data, which has been approved by a scientific consensus either through an impartial expert panel composed of scientists with contrary views, or through a critical peer review process.
- The possibility of a manipulation of data by a group, organization or industry with vested interests should be avoided at all costs.
- The calculations should encompass the entire population affected by the catastrophe and should give special consideration to groups with heightened vulnerability.
- Clinical findings should be thoroughly assessed and included in the final considerations.

Downplaying health effects

The IAEA, WHO and the nuclear industry assert that the death toll of the disaster at Chernobyl was 31, later raised to 'less than 50'. This indicates that only the victims of deterministic (non-stochastic) effects, who died within days, weeks or months have been counted.
The death toll world wide of the Chernobyl disaster is estimated at nearly one million people (Yablokov et al. 2009), see also Chapter 3 *Observed health effects*. In addition to these victims there are innumerable people with incurable diseases and malformations following the disaster in 1986. These estimates are based on publications in Russian from Russia, Belarus and Ukraine, which the IAEA and WHO do not include in their assessments.

According to an analysis based on radiological data provided by UNSCEAR, the Union of Concerned Scientists estimates that, among the hundreds of millions of people living in broader geographical areas, there will be 50 000 excess cancer cases resulting in 25 000 excess cancer deaths [UCS 2011]. For this broader group, the report [TORCH 2006] predicts 30 000 to 60 000 excess cancer deaths. A Greenpeace report puts the figure at 200 000 or more [Greenpeace 2006]. These estimates are not discussed by the IAEA and WHO; the reports are not even mentioned in their official reports.

On 31 May 2013 the UN Information Service published a press release [UNIS 2013] Q352 stating:

> "Radiation exposure following the nuclear accident at Fukushima-Daiichi did not cause any immediate health effects. It is unlikely to be able to attribute any health effects in the future among the general public and the vast majority of workers," concluded the 60 th session of the Vienna-based United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR).

UNSCEAR in its report [UNSCEAR 2013b] stated concerning the Fukushima disaster:

> "No discernible increased incidence of radiation-related health effects are expected among exposed members of the public or their descendants."

At present the IAEA, WHO, UNSCEAR and nuclear industry are downplaying the health consequences of the Fukushima disaster which is classified as 'non-catastrophic'. The worst effects in the industrial view are economic losses, financial liabilities and less support for new nuclear power stations.
Assertions such as "no casualties", "no ill effects" or "no ill effects expected" are misleading at best, because they are not supported by any independent epidemiological investigation among the affected people.
The long latency periods of stochastic health effects due to radioactive contamination may give the nuclear industry the opportunity to downplay those effects and even to deny in many cases that radioactivity caused the observed adverse health effects. Other factors are blamed as the cause of observed disorders, such as psychosomatic factors: 'radiophobia', the anxiety about radiation.

In their reports on the effects of Chernobyl and Fukushima the IAEA/UNSCEAR/WHO do not recognise non-cancer diseases as possible radiogenic health effects. As far as known no investigations are done of other health effects that harms the quality of life, such as deterioration of the digestive tract, immune system, sensory functions (primarily eyes), reproductive function and physical depression.

Limited scope of IAEA/UNSCEAR/WHO investigations

In the reports from the IAEA and WHO regarding the health effects of the Chernobyl disaster little or no attention is paid to ill effects other than acute radiation sickness.
Only in recent years has thyroid cancer been added to the list of the IAEA and WHO. The relationship between the incidence of thyroid cancer and exposure to radioactive iodine is obvious, the latency period is relatively short, compared to many other radiation-induced cancers.
The direct relationship between exposure to radionuclides other than radioiodine and the incidence of cancerous and non-cancerous diseases is much harder to prove. Only by means of extensive epidemiological surveys of large numbers of people over the course of many years can these relationships be unambiguously proven.
Future investigations of the health effects of the involved people will be seriously hampered by the fact that systematic and relevant measurements of contamination by different kinds of radionuclides have been left undone. All biologically active radionuclides should be included in the investigations, not just easily detectable radionuclides like cesium-137 and the short-lived iodine-131. We found no indications that the IAEA, UNSCEAR and/or WHO ever performed such investigations nor that they intend to do so in the future.

Understandably an investigation of the consequences of radioactive contamination will start with the easiest observable phenomena. Limiting the investigation to just these, hardly deniable, observations points to unsciemtific behaviour and a biased attitude. Another source of bias in the investigation of the consequences of a large-scale accident may be the basic assumptions behind the choice of the groups within the affected population that are surveyed and which are not.

Ignorance and 'fear of the unknown'

The World Nuclear Association in its publications attributes objections to nuclear power to ignorance and the "fear of unknown: the invisibility of radioactivity and radiation and its insidious health effects". People with objections to nuclear power are inferred to be ignorant of the safety and robustness of nuclear technology and its benefits. This view is often substantiated by arguments such as:

- Fear of radiation hazards is unjust, because nuclear plants would release only a fraction of what everyone gets from natural sources in the environment.
- Risks everyone faces in daily life are hundreds of times greater than those from nuclear power, according to nuclear advocates.
- The small number of casualties from even the worst accidents, a small fraction of the deaths from other energy technologies, endorses the outstanding safety record of nuclear power.

Effects observed in the environment, and no effects in humans?

The consequences of the radioactivity for the plant and animal life in the contaminated regions after the Chernobyl disaster are being investigated by a number of scientists from the USA, Japan and Europe. A case study of Chernobyl wildlife chronically exposed to low dose rates revealed that animals living in the wild are about 8 times more sentitive to radiation than previously thought. The scientists found strong effects of ionizing radiaion from Chernobyl on mutation rates.
One of the remarkable findings is that the number of syllables in Chernobyl cuckoo calls reliably indicate habitat, soil and radiation levels [Mousseau et al. 2016].

Figure 10
Difference in width of tree rings in pine logs from Chernobyl. The year of the accident in 1986 is clearly visible from the change in color of the wood. This figure is from the publication [Mousseau et al. 2013].

One of the findings are the adverse effects on the growth of pine trees in the contaminated areas, see the photograph in Figure 10. One may wonder what are the long-term effects of radioactive contamination for humans, in view of the pronounced effects for trees? It seems improbable that chronic exposure to many different radionuclides, even at 'low' levels, would not have human health effects. A group of independent researchers found also significant effects in wildlife in the region affected by the Fukushima disaster, such as genetic damage and ecological differences [Mousseau at al. 2014], [Mousseau et al. 2016].

Passing over non-radiogenic nuclear health effects

After the disasters of Chernobyl and Fukushima hundreds of thousands of people were forced to evacuate from their homes and villages, often permanently. Obviously the disasters had and still have a huge impact on the lives of these people, and also on other inhabitants in contaminated areas. According to official data nearly 2000 people died from the effects of forced evacuations [Fairlie 2016b]. Numbers of deaths among the forced evacuees following the Chernobyl disaster are not known or not published.
The IAEA/UNSCEAR/WHO reports on Chernobyl and Fukushima state that these deaths are not caused by radioactivity but by 'radiophobia'. The reports state that the phenomenon they called 'radiophobia' is unjust and the fault of the people themselves, so those consequences are not the responsibility of the nuclear industry. Indeed, radioactivity may be not the direct cause, the nuclear disaster is the direct cause. The situation for the hundreds of thousands residents in the contaminated areas of Chernobyl and Fukushima may be compared with a conflict zone in a war. How does the IAEA reconcile human suffering on the scale of Chernobyl and Fukushima with the claimed robust safety of nuclear power?

Scientific texts do not appropiately reflect the deep and long-lasting human suffering resulting from a nuclear accident. Therefore the following quote from [Jacobs 2016]:

> "The most powerful legacy of Chernobyl, besides its long-lived radiation, is the widespread use of the word "radiophobia" by nuclear industry apologists to describe the public response to large releases of radiation: fear. Look for this word and sentiment in the many articles being published this month about Fukushima. When you see it, or read the claim that more people were harmed at Fukushima by their own irrational fears than by radiation, you are seeing the work of forgetting turn its cruel wheels. Behind those wheels are the shattered lives and emotional wellbeing of hundreds of thousands of people whose communities were destroyed, and whose families were ripped apart by the Fukushima disaster. People whose anxieties will rise every time they or their children run a high fever, or suffer a nosebleed or test positively for cancer. People whose suffering - at no fault of their own - is becoming invisible. Soon when we talk about Fukushima we will reduce the human impact to a quibbling over numbers: how many cases of thyroid cancer, how many confirmed illnesses. Lost-hidden-forgotten will be the hundreds of thousands of people forced to flee their homes, in many cases permanently, and try to rebuild their shattered lives. Public relations professionals and industry scientists will say that these people did this to themselves (...). And the curtain will draw ever downward as we forget them.
> This is the tradition of nuclear forgetting.
>
> Some of the difficulty in remembering those affected by nuclear disasters is systemic, and some is strategic. Radiation is difficult to understand. Exposure to radiation embodies what Rob Nixon describes as slow violence, "formless threats whose fatal repercussions are dispersed across space and time."1 The slow impact of the catastrophe of nuclear disaster dislocates it from the disaster itself. The news cameras of the world were focused on the Fukushima Daiichi plants while they were exploding, but as the fallout of those plumes settled to earth, other catastrophic events drew our collective gaze elsewhere. Most health effects from exposure to radiation unfold over years and blend into the low moan of tragedies that afflict people in their personal lives, uncoupling from the events that caused them by our perception of the passage of time."

Little is known about the consequences of disaster at Mayak (also known as the Kyshtym disaster) in the East Urals in 1957 [Kyshtym 2015]. The few available reports point to consequences comparable to Chernobyl and Fukushima.

7 Questionable assessment methods

‘We know it all’ attitude

During the years following the Chernobyl disaster in 1986 the IAEA, WHO and the nuclear industry insisted that the death toll of the disaster was only 31 people. Apparently only the registered victims of deterministic radiation effects, who died within hours to months, have been counted.
The lethal effects of contamination by radioactivity at lower levels than would cause deterministic effects generally have long latency periods, often years to decades, a well-known fact within the IAEA and WHO. In addition the registration of victims during the hectic time after a disaster usually is imperfect or even absent. The effects of chronic exposure to low doses of radionuclides via food and water are unknown.
For the reasons above it is untrustworthy and unscientific to state without reservation a definitive number of casualities shortly after the disaster and to present that number as if it were conclusive and indisputable.
The World Health Organization in its Joint News Release WHO/IAEA/UNDP [WHO 2005] states :

> ‘As of mid-2005, however, fewer than 50 deaths had been directly attributed to radiation from the disaster, almost all being highly exposed rescue workers, many who died within months of the accident but others who died as late as 2004’

This number of ‘fewer than 50’, also quoted at the UN Chernobyl Forum in Vienna in September 2005, cannot be true for the same reasons, according to [IPPNW 2011].

Notable is the absence of a reference to solid statistical databases of the incidence of various diseases within large cohorts of people, living in specified regions, according to level of contamination. References to medical reports following the affected people over a significant number of years are also lacking.

In 2005 the WHO published a publication in its Media Centre [WHO 2005] titled: *Chernobyl: the true scale of the accident. 20 Years Later a UN Report Provides Definitive Answers and Ways to Repair Lives*. This media document refers to the Chernobyl Forum in 2005. The title itself raises questions about its scientific quality.
What is the ‘true scale’? How is that scale assessed?
What are ‘definitive answers’? Does that mean ‘conclusive’ or ‘subject closed’?
Are ‘definitive answers’ possible less than 20 years after the disaster?
Are ‘definitive answers’ possible without large-scale independent medical and epidemiological investigations during a period of decades?
Large areas are heavily contaminated with a gamut of radionuclides, redispersion of radioactive particulate matter occurs continually by wild fires. People in the contaminated areas are chronically exposed to radioactive materials via inhalation (gases, dust) and ingestion (food, water).
All the above statements point to an unscientific attitude of “we know it all”.

The claim that there will be no more than 4000 fatalities resulting from radiological consequences of the accident is grossly misleading [Baverstock 2016]. According to careful studies led by the International Agency for Research on Cancer (IARC) the figure is several times higher.

Downplaying without proof

Illustrative of the downplaying and unscientific attitude of the IAEA with regard to the disaster at Chernobyl is the statement of Hans Blix in 1986, then chief of the IAEA:

> “The atomic industry could take a catastrophe like Chernobyl every year.”

At that moment it was impossible to attain a reliable insight into the consequences of the disaster, even today it is not possible.

The credibility of the IAEA and WHO suffered further when it turned out that both institutes had seriously manipulated the data their presentations were based on at the Chernobyl Forum. As [IPPNW 2011] put it:

> " . . . it can be rationally concluded that the official statements of the IAEA and the WHO have manipulated their own data. Their representation of the effects of Chernobyl has little to do with reality."

Ignoring diverging data and avoiding scientific discourse

An independent assessment estimated the death toll world wide of the Chernobyl disaster at nearly one million people [Yablokov et al. 2009]. This estimate is based on numerous publications from Russia, Belarus and Ukraine, publications the IAEA and WHO did not include in their studies. In addition to the casualties there are innumerable people with incurable diseases and malformations following the disaster in 1986. These studies are ignored by the IAEA and WHO. The findings of Yablokov et al. are broadly endorsed by an elaborate study by the German Affiliate of Nobel Prize winner International Physicians for the Prevention of Nuclear War (IPPNW) and of the Gesellschaft für Strahlenschutz [IPPNW 2011] and [IPPNW 2013].
In the IAEA/UNSCEAR/WHO reports we found no discussion of scientific reports with results diverging from their own view; even the existence of such reports are not mentioned.

The conclusions of the IAEA and WHO seem incompatible with those of many other studies. Why do these international institutions ignore the divergent results of other studies? If other studies are wrong, the results should be refuted by means of scientific arguments, not by ignoring them. Only then is a genuine scientific and transparent discussion on nuclear hazards possible.
Ignoring evidence that is not compatible with your own opinion is a fundamental scientific failure. When confronted with diverging results of other investigations of the same subject there are three options for a genuine scientist:

- the results of the other studies are wrong and you have to prove that based on verifiable scientific arguments,
- your own conclusions are wrong and you have to modify your theory and conclusions, incorporating the results of the other studies,
- studies on both sides are wrong or incomplete and should be revised.

A basic principle in science is that observations must be reproducible by other investigators in order to be recognized as reliable empirical evidence.
Apparently the IAEA and WHO did not deem it necessary to comply with this elementary scientific rule of conduct.

One of the findings of the study [IPPNW 2011] is:

> "The United Nations pro-nuclear organs such as the IAEA are attempting – with the use of questionable scientific methods – to minimise the effects of the catastrophe by inaccurate use of Chernobyl data. From a scientific point of view, this is unacceptable."

Models prevailing over empirical evidence: a fifth scientific flaw

Empirical data that deviate from the applied radiological models are ignored and observations of detrimental effects are attributed to non-nuclear causes if they don't fit the theoretical models used. If the nuclear industry cannot *prove* that there are no detrimental health effects of exposure to radioactive materials and radiation, a reasoning based on models is *not* a scientific proof. This practice is illustrated by the following quote from the WHO document [WHO 2005], also published in [Chernobyl Forum 2006]:

> "Because of the relatively low doses to residents of contaminated territories, no evidence or likelihood of decreased

> fertility has been seen among males or females. Also, because the doses were so low, there was no evidence of any effect on the number of stillbirths, adverse pregnancy outcomes, delivery complications or overall health of the childern."

With this statement the WHO commits a fundamental scientific flaw: reversal of argumentation by adapting the observations to the models the WHO believes in: 'not the theoretical models are wrong or imperfect , but the observations are (!)'. This may remind the reader a famous scene in the play *Leben des Galilei* by Bertolt Brecht, when the cardinals said to Galileo Galilei:

> '*We do not need to look* (in your telescope) *because it cannot be true*.'

Apart from this fundamental flaw the applied models are old and have a limited scope, as explained in Chapter 4. Moreover: the WHO *assumes* the doses were low, but there are no indications that these doses were actually *measured* among the affected population.
What is 'low'? According to which standard?
Which kind of doses does the WHO have in mind?
Just cesium-137 or also other nuclides?
Just external radiation or also contamination by radioactive materials, internal and external?
Which period is covered by the dose calculation?
Are the effects of chronic radioactive contamination accounted for?

Missing proofs: a sixth scientific flaw

The [WHO 2005] report pays much attention to 'mental health problems' and other issues:

> "Poverty", "lifestyle" diseases now rampant in the former Soviet Union and mental health problems pose a far greater threat to local communities than does radiation exposure."

and:

> "Persistent myths and misperceptions about the threat of radiation have resulted in "paralyzing fatalism" among residents of affected areas."

The WHO does not explain what they called 'myths and misperceptions'. Does the WHO know the exact impacts of poverty and lifestyle before the Chernobyl disaster?
Little attention is paid to physical ill effects. The WHO does not mention non-cancerous diseases as possible ill effects caused by radioactive contamination, but attributes these effects to other factors. These statements are not proven by investigations nor by scientific arguments. The [IPPNW 2011] study concludes:

> "An inadmissable chain of argument is often applied: non-cancerous – therefore not induced by radiation – therefore not a result of Chernobyl – end of debate."

In the reports of the IAEA and WHO the proofs of above assertions are missing: no investigations are performed or reported which would underpin these statements, so they appear just assumptions, without scientific value.
There appear to be few studies of psychosocial health effects (including deaths and suicides) published in the West following the very large forced evacuations after Chernobyl. In the future, it is recommended that deaths from evcacuation-related trauma, ill-health and suicides should be included in assessments of the fatalities from nuclear disasters (TORCH 2016]. Admittedly these fatalities are not directly caused by radiation, but they are an immediate consequence of a nuclear disaster.

No falsification of an unwelcome explanation: a seventh scientific flaw

Statements in which observed ill effects in radioactive contaminated areas are attributed to other than radiogenic causes without any scientific proof, which claim to definitively exclude radioactivity as a cause, also without any scientific proof, are highly questionable.
From a scientific point of view the assertions of the WHO quoted in the previous section are fundamentally flawed. If it is not possible to unambiguously prove that radioactivity *is* the cause of adverse health effects observed at a given time in a given region, and these ill effects are attributed to another cause, then it still has to be *proven* by means of sound scientific arguments that radioactivity cannot be the cause. Any assertion without restriction that radioactivity is not the cause but other factors are, has to be based on a sound scientific analysis (falsification procedure).

Another example of the absence of a necessary falsification is the following statement of the [WHO 2005]:

> "A modest but steady increase in reported congenital malformations in both contaminated and uncontaminated areas in Belarus appears related to better reporting, not radiation."

Apart from its questionable soundness the statement raises some questions, such as:
Why does a better reporting exclude radiation as cause?
Which areas in Belarus were 'uncontaminated'?
Which radionuclide(s) has/have been taken into account, and which have not?
Have all people in the contaminated and 'uncontaminated' areas been screened, or only a selected group?
During which period?
In view of the poor registration (if any) of the persons who were exposed to radioactivity, of the radioactive doses they contracted, and of the observed ill effects within the population in the affected areas, the above statement seems highly questionable, all the more so in view of the secrecy surrounding the data.

View of the IPPNW

By coincidence one month after the nuclear disaster at the Fukushima Daiichi niclear power plants in Japan, the report *Health effects of Chernobyl, 25 years after the reactor catastrophe* [IPPNW 2011] was published. The report was written by a team of authors from the German Affiliate of International Physicians for the Prevention of Nuclear War (IPPNW) and of the Gesellschaft für Strahlenschutz.
The IPPNW 2011 report is based on a large number of analyses which were found comprehensive and methodologically sound, not only papers that have been published in peer-reviewed journals. It includes serious analyses from scientists in Russia, Belarus and Ukraine which have been published in Russian and discussed at congresses in Russian that are almost completely ignored in the Western world.

One of the findings of the IPPNW study is:

> "Essential data on the course of events of the Chernobyl catastrophe and the subsequent effects on health are not publicly available. They are classified in both East and West. This makes independent scientific analysis of the effects of Chernobyl extremely difficult. The United Nations pro-nuclear organs such as the IAEA are attempting – with the use of questionable scientific methods – to minimise the effects of the catastrophe by inaccurate use of Chernobyl data. From a scientific point of view, this is unacceptable."

A quote from [IPPNW 2013]:

> The people of Fukushima are not being helped by claims and reassurances that no health effects are to be expected.

8 Flexibility of regulations

Which criteria for 'acceptable' risks?

Safety measures, such as exposure standards, quality control and the independence of inspections. are vulnerable to economic considerations and short-sighted actions. Economic pressure may enhance the health hazards of nuclear power.
De-regulation (liberalisation) of electricity markets has pushed nuclear utitlities to decrease safety-related investments and to limit staff [Hirsch et al. 2005].

The strained connections between economics and nuclear safety and health risks is clearly expressed in the French Roussely report [Roussely 2010]:

> 'La question du risque nucléaire acceptable, ou plus généralement du risque technologique acceptable, est un débat de société à part entière pour lequel la ou les réponses à donner sont naturellement du rôle du Politique. Force est néanmoins de constater que la notion même de compétitivité du nucléaire et l'hétérogénéite des règles de sûreté selon les Etats renforcent l'actualité de ce débat et la nécessité de préciser certaines exigences de sûreté. La seule logique raisonnable ne peut pas être une croissance continue des exigences de sûreté.'

In English translation:

> 'The question of what is an acceptable nuclear risk or, more generally, an acceptable technological risk, is a debate that concerns the society as a whole, one where the answer(s) provided will, naturally, have a political dimension. However, it must be noted that the concept itself of the competitiveness of nuclear power and the heterogeneity of the security regulations according to the States reinforce the relevance of this debate and the need to clarify certain security requirements. The only reasonable logic cannot be continued belief in security requirements.

Relaxation of clearance standards

The enormous, escalating costs of waste management and disposal may cause undesirable developments and hazardous situations. Regulatory standards may be relaxed to permit higher concentrations of radionuclides in materials released, for economic reasons. Clearance is the controlled release of materials into the public domain; once released the materials are no longer subject to regulation.
The IAEA [IAEA-293 1988] proposed to dilute radioactive materials with non-radioactive materials and to use contaminated concrete rubble as landfill or road paving. 'Weakly' radioactive steel scrap – however defined and measured – could be remelted with fresh steel and used for 'special purposes'. Reuse of 'low-activity' contaminated and/or activated steel and concrete by diluting it with fresh steel or concrete, as proposed by the IAEA, could be very risky for several reasons:

- the unknown but potentially hazardous isotopic composition of the scrap and rubble
- the unknown biological behavior of the radionuclides
- problematic detection of a number of radionuclides .
- uncertainties with regard to standards, inspection and control
- the high risk of uncontrolled and illicit trade in radioactive materials.

Also, its use, disposal and maintenance would no longer be controlled. Road work on contaminated roads would revolatize the radioisotopes as fine particulate matter (PM) where they become an inhalation danger and no longer qualify as low level exposure, because if they lodged in the body they would become internal emitters.

Findings of the National Council of Radiation Protection and Measurements [NRCP-141 2002], concerning potentially radioactive scrap metals, are indicative of an urgent and problematic situation in the USA:

'There is an urgency to establish consistent national/international policies and standards.'

In Europe, with its many different countries, the situation is far more complex and probably more problematic. In case of the waste released by dismantling nuclear power plants and other nuclear facilities, it would be wise to avoid shipments and trade of radioactive scrap metal and debris as much as possible by packing the materials at the source: the reactor or other radioactive instalation being dismantled.

Which criteria for 'allowable' radioactivity levels?

During the last days of the Bush Administation the US Environmental Protection Agency (EPA) proposed to allow radioactive contamination in drinking water at concentrations vastly greater than allowed under the Safe Drinking Water Act. The new standards permit public exposure to radiation levels vastly higher than EPA had previously deemed unacceptably dangerous [PEER 2009]. In its proposal EPA increased permissible public exposure to radiation in drinking water with factors of 1000 to 100000 involving the nuclides ^{90}Sr, ^{131}I and ^{63}Ni. What about ^{129}I? If ^{131}I is present, ^{129}I is also present. In the most extreme case the new standard would permit radionuclide concentrations 7 million times more lax than permitted under the Safe Drinking Water Act. Other aspects of the new EPA proposal are lax cleanups and higher exposures to other sources, such as relaxed dirty bomb standards.
The proposal was initially blocked by the incoming Obama Administration. But in the final months of the Obama Administration the White House has allowed the EPA to approve even higher levels of radioactive contamination, which is now awaiting only the final public comment period [Global Research 2014] [PSR 2016].

EPA has not provided scientific or medical evidence of why the Protective Action Guides (PAGs) should be relaxed, even though relaxinf them could increase the cancer deaths of exposed Americans several hundred-fold. Physicians for Social Reponsibility [PSR 2016] stated:

> All radionuclides can cause cancer and other health and reproductive problems; there is no completely safe level. Strontium causes bone cancer and leukemia. Babies, children, and females are at even greater risk than adult males.
> PAGs apply not just to emergencies such as "dirty bombs," and Fukushima-type nuclear power meltdowns but also to any radiological release for which a protective action may be considered – even a radiopharmaceutical transport spill. The proposed drinking water PAG would apply not to the immediate phase after a release, but rather to the intermediate phase, after the release has been stabilized, and lasting up to several years thereafter.
> Radiation doses (in rems) cannot be measured but are calculated based on some measurements and many assumptions. The current Safe Drinking Water Act limits are based on 4 millirems per year. The PAGs would allow 500 millirems per year for the general population. A single chest X-ray gives about 2 millirems. Because of the way EPA is changing the definition of dose, for many radionuclides, the allowable concentration would be thousands, tens of thousands, and even millions of times higher than set under the Safe Drinking Water Act.

Ageing nuclear power plants and other facilities containing large amounts of materials at high levels of radioactivity are in their wear-out phase, characterized by, among other, an increasing incidence of failures, leaks and unplanned releases of radioactive materials into the environment. Relaxation of emission regulations might be a means to make lifetime extension of ageing nuclear power plants economically viable.
In view of the reliance on models within the nuclear industry and the ease to adapt models to changing needs of the nuclear industry, any relaxation of standards should be based on verifiable empirical evidence.
What is the situation in Europe, Russia, Asia?

Regulations and quality control

On base of what scientific and medical evidence would the qualifications be defined such as: 'weakly' radioactive, 'low-activity' and 'special purposes'?
Who controls the sorting of the materials into the categories: 'free release', 'to be diluted' and 'waste'?
How are 'special purposes' defined and how is 'restricted reuse' controlled?
Of what radioisotopic composition is the radioactive component in the debris or scrap? Has that composition been measured or has it been estimated based on models from the early 1970s? What is known about the biomedical activity of the radionuclides in the debris and scrap? Another issue is the difficulty in detection of a number of hazardous radionuclides.
In view of the large problems already existing with regard to illicit trade and smuggling, great risks loom here, even without relaxing the standards. Large volumes and masses of debris and scrap, sometimes of high value on the free market, are involved in decommissioning and dismantling nuclear facilities. Experiences in the past concerning waste handling by private companies are not always encouraging in this respect.
If the handling and management of radioactive debris is left to private companies, profit seeking may prevail over safety and health. Financial motives for short-term 'solutions' may be backed by financial constructions which leave the liability for failures and mishaps with the customer, in this case the taxpayer. Such financial constructions seem to be involved in the contracts for decommissioning and dismantling of the Sellafield reprocessing plant under the authority of the British Nuclear Decommissioning Authority [NDA 2006].

How independent are the inspections?

Economic arguments may also lead to reduced quality controls by official inspectors. Several incidents at nuclear power stations in the USA during the past years point to such a development. In a number of countries the nuclear industry urges simplified and shortened license procedures to speed up the construction of new nuclear builds, with minimalisation or even elimination of the participation of the local authorities and the public. It is conceivable that even the independence of the regulatory agencies would be liable to suffer under economic pressure. The above described relaxation of the exposure standards by the US EPA points in that direction. What is the situation in other countries?

The Roussely report [Roussely 2010] calls for a reduction in the scope, and as a result a reduction of the independence of the French Safety Authority ASN (Autorité de Sûreté Nucléaire):

> 'En France, il convient que l'État définisse un modus vivendi équilibré avec l'Autorité de Sûreté, c'est-à-dire réaffirme le rôle régalien qu'il ne devrait pas abandonner à une autorité indépendante.
> … Il convient d'éviter que des événements de portée très limité conduisent à jeter une suspicion injustifiée sur l'ensemble d'une technologie.'

In English translation:

> 'In France, the government must define a balanced modus vivendi with the Safety Authority, and re-establish their sovereign authority which it should not relinquish to any independent authority.
> … The goal being to prevent events with very limited effects resulting in unjustified suspicion of a technology as a whole.'

In this case, which independent authority judges an event, e.g. an incident or design error, to have 'very limited effects' not only at the moment of discovery but also in the long run?
Who decides for what reasons an 'event with very limited effects' might or might not cast 'unjustified suspicion of a technology as a whole', in this case of nuclear technology?
The decision process on nuclear power in France is controlled by the president and the Corps des Mines (a technocratic elite), effectively without the participation of the parliament [Schneider 2008].

9 Prospects

Problems for the future

Most likely the frequency and seriousness of releases of radioactive materials into the environment will increase with time due to several factors, such as:

- Increasing amounts of radioactive materials are piling up in a growing number of temporary storage facilities. Because no definitive and safe disposal facilities are operational some fraction of these materials will escape into the environment due to inherent deficiencies of technical systems and human behaviour.
- Unavoidable deterioration of materials and structures of spent fuel elements and of temporary storage facilities of radioactive wastes, as a consequence of the Second Law of thermodynamics, enhanced by the nuclear radiation from the waste. Due to these ageing processes the fraction of the radioactive waste escaping into the environment likely will increase with time, as well as the risks for large nuclear accidents.
- Escalating costs and a growing backlog result in increasing economic pressure, exacerbated in the case of periods of economic decline. These factors may cause:
  - decrease of safety-related investments and staff at nuclear power plants and at other nuclear facilities
  - relaxation of official discharge and clearance standards and regulations
  - less frequent and less independent inspections
  - increasing tendency to conceal failures, leaks and shortcomings
  - search for cheaper ways, and consequently less effective ways, to store increasing amounts of radioactive waste
- Illicit trafficking will likely increase as a consequence of the above mentioned factors. Illegal trade and smuggling of radioactive materials and equipment is already a significant problem, little numerical data have been published.
- A related problem is the illegal dumping of radioactive waste at sea or in sparsely inhabitated regions.
- Nuclear facilities are vulnerable to terroristic attacks, possibly initiating severe accidents. Severe accidents could also be initiated by hostile actions in an armed conflict anywhere in the world. The consequences of an accident like the Chernobyl and Fukushima disasters do not stop at national borders.
- Postponing adequate waste management solutions to the future for economic reasons increases the risks of nuclear terrorism: dirty bombs dispersing radioactive materials or even primitive nuclear explosives made from MOX fuel. The risks may be growing due to the increasing threat of terroristic organizations.
- Accidental and inadvertent releases of radioactivity into the environment, including large-scale accidents, can also be caused by natural disasters. As growing amounts of radioactive materials are present within the human environment and adequate actions are delayed longer, the risks of disasters grow and the amounts released may grow as well.
- Nuclear power plants that are beyond their original design lifetime are now in their wear-out phase, characterized by a growing failure rate of technical systems. Lifetime extension greatly enhances the risks of large-scale accidents, their frequencey as well as their severity. The same holds true for the ageing spent fuel cooling pools, high-level waste storage facilities and reprocessing plants. This development comes on top of the unpredictable risks of natural disasters and terroristic attacks.

Energy on credit, the energy debt

A contributing factor to increasing health hazards in the future may be the 'living-on-credit' culture within the nuclear industry, featuring systemic postponement of radioactive waste management actions to the future. Only a small part of these actions cannot be performed at this moment, namely the definitive disposal in a geological repository of spent nuclear fuel younger than about 30 years, because of the residual heat generation of these materials. However, the postponement of the final safe disposal of the majority of radioactive wastes has no technical reasons, but is likely attributable to economic arguments. This also holds true for the dismantling of the numerous permanently closed down nuclear power plants and other nuclear facilities.

Likely the postponement paradigm will result in the shifting off the responsibility and liability for safe nuclear waste disposal to the taxpayer and to future generations.

- Who can guarantee that the presently operating owners/operators of nuclear power plants will still exist as viable entities 100-150 years from now?
- If so, who can guarantee that these companies will be willing and be able to fulfil the tasks of their inherited responsibility dating from 100-150 years ago?
- Who can guarantee that 100-150 years from now sufficient highly skilled personnel will be availaible to perform the tasks our generation could not, for whatever reason?
- Who can guarantee that 100-150 years from now the required expertise, the required documentation and technical knowledge will still be available to perform the ever growing tasks?
- Who can guarantee that the dismantling funds set aside by the currently operating NPPs will still exist 100-150 years from now?

Even if all these conditions are met, and even if the interest rate during the next century remained at 4%, the resulting sum of money would be only a fraction of the amount really needed at that moment in the future. The energy debt increases with time due to Second Law phenomena, even if no new radioactive materials were to be generated from this moment on. An increasing energy debt implies that increasing amounts of energy, materials and human effort will be required to perform a given task, the longer the task is postponed.

The first preliminary estimates of the costs of dismantling nuclear power plants and reprocessing plants point to amounts of hundreds of billions in the United Kingdom [NDA 2015]. These costs almost certainly will rise significantly during the actual operations that may take 100-130 years. Massive cost overruns are to be expected in such large-scale first-of-a-kind projects; history shows that cost escalations are the rule within the nuclear industry. The cost estimates of dismantling the Swiss nuclear power plants [SWI 2011c] and of the small West Valley reprocessing plant in the USA [UCS 2007] are not encouraging, as little as the cost estimates of the cleanup of the Hanford Site in the USA [DOERL 2015]. How about the costs of the dismantling of the numerous nuclear power plants, reprocessing plants and other nuclear facilities in France and other countries?
Obviously a heavy economic burden may lead to less optimal choices, evoking increased health hazards.

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