# IN CAUDA VENENUM

## HEALTH RISKS OF NUCLEAR POWER

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## Abstract

This study starts with a physical assessment of the quantities of the radioactivity being generated and mobilied by the entire system of related industrial processes making civilian nuclear power possible. It assesses the actual and potential exposure of the public to human-made radioactivity, and it discusses empirical evidence of harmful health effects of these exposures. The biomedical effects of radionuclides in the human body are briefly discussed.
Furthermore this study analyses the mechanisms which may cause the uncontrolled dispersion of very large amounts of radioactivity into the environment. The study explains some consequences of a basic law of nature (Second Law) for the health risks of nuclear power now and in the future. Misconceptions, uncertainties and unknowns of the nuclear safety issue are addressed. Risk enhancing factors are discussed, along with the consequences of the present economic paradigm for the health risks of nuclear power at this moment and in the future.
The hazards of nuclear power just do not stop at the reactor: what happens and what will happen with the human-made radioactivity? In causa venenum.



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In cauda venenum

A Latin phrase from ancient Rome, meaning: the poison is in the tail. Using the metaphor of a scorpion, this can be said of a story or development that proceeds gently, but turns vicious towards the end.

# Summary and results

Assessment of the health risks posed by nuclear power is an intricate issue with a number of different aspects.
One aspect concerns the biomedical aspects van radioactivity in the human body and empirical observations of radiation-induced diseases.
Another aspect comprises technical features of the civil nuclear energy system: the generator of human-made radioactivity and the possible technical means to keep the human-made radioactivity out of the human environment.
A third aspect has to do with the pathways along which human-made radioactivity can enter (and is entering) the human environment. Technical as well as non-technical factors are playing an important role.
A fourth aspect comprises the views of the nuclear industry on safety of nuclear power and health effects of radioactivity and the ties between the nuclear paradigm and economic interests.
A fifth aspect concerns the communication on nuclear matters between the nuclear world at one side and decision makers and the general public at the other side.

**Scope of this study**

Starting point of this study are the following observations:

- Nuclear power is inextricably and irreversibly accompanied by the generation of immense amounts of human-made radioactivity.
- Radioactivity cannot be destroyed.
- Radioactivity cannot be made harmless to humans.

This study is based on a scientific and technical life cycle assessment (LCA) of the complete system of industrial activities needed to generate nuclear power, from cradle to grave. The analysis applies basic physical laws and conserved quantities, such as: energy, mass, amounts of radioactivity. This approach implies a global perspective and a long time horizon, because the full cradle-to-grave period of a nuclear power plant may easily come to 100-150 years and the nuclear-related activities of the process chain are spread across the continents.
Moreover, the consequences of nuclear power with respect to adverse health effects may attain global proportions.

Economic and financial aspects are not addressed.

The study focuses on a unique feature of nuclear power, no other energy system has: the generation of human-made radioactivity and how to cope with it. Non-radioactive substances originating from the nuclear energy system posing health risks are not included in this study to limit its scope.

**Biomedical effects of radioactivity**

Radiology discerns two kinds of health effects of nuclear radiation in the human body: stochastic effects and non-stochastic (deterministic) effects.

*Non-stochastic (deterministic) effects*
Non-stochastic effects, also called deterministic effects, occur after exposure of a person to very high doses of nuclear radiation, for example in the vicinity of a nuclear explosion or near unshielded spent fuel. In such cases there is an evident causal connection between dose of radiation contracted and health effects, which become manifest within hours, days or weeks. These effects are usually called acute radiation syndrome (ARS) or radiation sickness.
The nuclear world as represented by the International Atomic Energy Agency (IAEA) tends to count only deaths by ARS as victims of a nuclear disaster (e.g. Chernobyl).

*Stochastic effects*
This name points to the stochastic character of the health effects: the effects become manifest at random within a cohort of exposed people: there will be effects, however, it is not predictable which effect will develop with which person and after which period.

The biological effects of radiation in living cells, especially in combination with the presence of various radionuclides inside the human body are a very complex matter, with many unknowns. The direct relationship between the exposure to a relatively low dosis of nuclear radiation (i.e. a dosis other than directly lethal) and the resulting adverse health effects on individual scale is very difficult to prove for a number of reasons, such as:

- long latency period (often years to tens of years) between exposure and observable health effects
- stochastic character of radiation-induced health effects
- effects of other factors (age, gender, physical condition, non-nuclear chemicals, etcetera)
- synergistic effects of a number of radionuclides in the human body together
- basic biomedical unknowns.

Extensive epidemiological studies can provide the empirical evidence of the relationship between radiation and health effects within large groups of individuals.

Exposure to radionuclides and nuclear radiation can cause carcinogenic, mutagenic and teratogenic effects, causing cancerous diseases, such as solid cancers and leukemia, but also non-cancerous diseases, such as: premature biths, low birth-weight, infant mortality, congenital defects and chronic diseases (e.g. immune system, diabetes).

The health effects of all different types of radionuclides within the human body are not well understood and the biochemical mechanisms are poorly investigated.
Furthermore there is strong empirical evidence that damage also occurs in cells not directy hit by radiation: the so-called non-targeted and delayed effects (e.g. the bystander effect), via unknown mechanisms. Adverse health effects from low radiation doses might be far more serious than previously assumed on the basis of the classic dose-effect models.

Two major studies (German KiKK and French Geocap) revealed that the incidence of leukemia and solid cancers among young children living near nominally operating nuclear reactors has increased significantly. The results have been affirmed by other studies.
Empirical evidence proves the dose-effect models to be unable to explain observed health effects of routine releases from nominally operating nuclear power plants.
Apparently these observations do not stimulate a reconsideration of the benefits of nuclear power.

## 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 comprises:

- front-end processes:
  the industrial activities needed to produce nuclear fuel from uranium ore,
- mid-section:
  construction of the nuclear power plant, operation, maintenance and refurbishments of the power plant during its operational life,
- back-end processes:
  the industrial processes needed to handle the human-made radioactive waste and to keep it out of the human environment forever.

The cradle-to-grave (c2g) period is defined as the timeframe from the extraction of the first kilogram of uranium used by the system from its ore, through the definitive storage of the last kilogram of radioactive waste generated by the system in the safest conceivable way. The c2g period turns out to cover a timeframe of 100-150 years, an unprecedented period.
The LCA proveds 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 major uncertainties and unknowns which prove to be of great importance with respect to the viability and safety of nuclear power now and in the future.

Nuclear power involves the mobilisation of naturally occurring radioactivity and the generation of human-made radioactivity, a billionfold of the mobilised natural radioactivity. Each reactor of 1 GWe power generates each year as much radioactivity as 1000 exploded nuclear weapons (Hiroshima bombs). Up until this moment adequate solutions to immobilise and isolate the human-made radioactivity from the human environment exist only in cyberspace. All anthropogenic radioactivity ever generated is still present in mobile state within the human environment, stored in temporary facilities, which are increasingly vulnarable to accidents. The nuclear process chain is an unfinished technical system.

## How to cope with the human-made radioactivity

Human-made radioactivity ends up in broadly 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 and is heat generating for hundreds of years. The other waste stream has a very large volume and contains the balance of the radioactivity. This second waste stream consists of the operational waste from the processes of the nuclear chain and the dismantling wastes. Dismantling waste is released when nuclear reactors and other radioactive contaminated facilities, including reprocessing plants, are decommissioned and dismantled.

The only way to prevent 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 has to be opened, comprising a hundred kilometers of galleries with holes to store the heat generating spent fuel canisters. To dispose of the existing inventory of spent fuel from the past 10-15 of such deep geologic repositories would be required.
Safe storage if the other radioactive waste requires construction of another type of deep geologic repository, comprising very large caverns to store the containers with the operational and dismantling waste.
At this moment (2013) not a single geologic repository exists in the world.

**Radioactive waste management: current practice**

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. Within the foreseeable future the waste containers will go leaking at an increasing rate, due to inevitable degrading processes. 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 loss of knowledge can occur within a few decades. 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 into the seas. At present illegal dumping at sea is still occurring.

Nuclear industry frequently promotes two technological concepts as a reduction of the nuclear waste problem to easy to handle 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 is worsened by their implementation. The main cause of the fallacies is ignorance of one of the most basic laws of nature, the Second Law of thermodynamics, as will be briefly explained below.

**Vitrification of high-level waste**

High-level waste, as meant by the nuclear industry in this context, consists of the fission products + actinides from spent fuel. In order to be able to vitrify this fraction, spent fuel has to be reprocessed.
Reprocessing is the chemical and physical separation of spent fuel into uranium, plutonium and the highly radioactive fraction consisting of fission products + actinides. Reprocessing has been developed during the 1940s to retrieve plutonium from spent fuel from special nuclear reactors, for use in atomic weapons. During the 1960s and 1970s a civil version of reprocessing

has been developed to produce plutonium for breeder reactors. The breeder reactor system proved to be technically unfeasible, a consequence of the Second Law. Actually reprocessing of spent fuel has become a superfluous nuclear process, burdening the society with exceedingly high costs.

In the reprocessing sequence all gaseous fission products are released into the environment. Separation processes never go to completion and as a consequence a portion of the radionuclides set free from spent fuel remain in the waste streams of the reprocessing plant, particularly the highly soluble radionuclides.
Not all radionuclides can be vitrified (fixed into a glass matrix), so a considerable portion of the highly radioactive waste has to be stored otherwise. Significant fractions of these non-vitrified wastes are discharged into the environment, partly unavoidably as a consequence of the Second Law, partly for economic reasons.

Reprocessing generates a serious terroristic threat. MOX fuel (a mix of uranium oxide and plutonium oxide) can be separated with elementary chemistry into uranium and plutonium. The plutonium can be used in a crude but effective atomic bomb. The required technology is within reach of terroristic groups. MOX fuel is used in a number of civil nuclear power stations.

A nuclear energy system including reprocessing and plutonium recycle (MOX fuel) has a negative energy balance, if measured from cradle to grave.

Reprocessing leads to a huge volume increase of the radioactive waste and to massive discharges of radioactivity into the environment. Reprocessing turns out to be exceedingly polluting and greatly enhancing the health risks of millions of people and the chance of large-scale nuclear accidents.

**Partitioning & transmutation**

Partitioning & transmutation is a concept which would reduce the amount of radioactivity and/or the longevity of the radioactivity of high-level radioactive waste.

Partitioning is an advanced and extremely demanding version of reprocessing, the spent fuel has to be separated into a larger number of fractions (partitions) than conventional reprocessing. The required high separation specifications (purity and absence of losses) are not feasible, as a consequence of the Second Law.

In practice partitioning & transmutation is unfeasible, because the concept is based on 100% separation efficiency and on the availability of 100% perfect materials. Both prerequisites are impossible as a consequence of the Second Law.
Even if the concept would work as advertised it would take centuries (!) to reduce the existing amount of long-lived radionuclides to 10% of the original.
Besides, not all long-lived radionuclides can be transmuted into short-lived or stable nuclides.

The total amount of radioactivity greatly increases by partitioning & transmutation. For each long-lived radionuclide transmuted or fissioned several other radionuclides come into being, partly shorter-lived but also radionuclides with long half-lifes.

The health risks resulting from dispersion of radioactive materials into the human environment would increase by implementation of a partitioning & transmutation system, assumed it would work, due to an increased amount of human-made radioactivity and to the distribution of the radioactive materials over an increased number of vulnerable facilities.

In addition, nuclear power including partitioning & transmutation has a strongly negative energy balance, if measured from cradle to grave.

**Pathways of radioactivity dispersion into the human environment**

Nuclear health risks are posed by the dispersion of radioactive substances into the environment. Human-made radioactivity at the moment of its generation is contained in the spent nuclear fuel and comprises dozens of different radionuclides, representing all possible decay modes and nearly all elements of the Periodic Table. A large number of the generated radionuclides have very long half-lives: thousands to millions of years. Even after a cooling period of 100 years the specific radioactivity of spent fuel is still at such a high level that about 1 milligram of it ingested or inhaled would mean a lethal dose to a human.

Several categories of events leading to the dispersion of radioactivity into the environment may be distinguished:

- Authorized routine discharges of radioactive substances by nuclear power plants and other nuclear facilities, for example reprocessing plants. The authorised discharges, occurring day by day, are officially classified as harmless; measurements of their magnitude are usually unknown in the public domain. Epidemiological studies proved routine releases of radioactivity by nominally operating nuclear power plants to be harmful.
- Unplanned, unauthorised discharges. Leaks and small accidents at nuclear power plants or other nuclear facilities, such as interim storage facilities and reprocessing plants, occur frequently and often unnoticed for long periods. Amounts of discharged radioactivity vary widely, but may be very large.
- Illegal trade and smuggling of radioactive materials and equipment is already a significant problem, little or no numerical data have been published. A related problem is the illegal dumping of radioactive waste at sea or in sparsely habitated regions.
- Large-scale accidents of Chernobyl-Fukushima type, dispersing huge amounts of radioactivity over vast areas and affecting millions of people. Radionuclides from these sources are measurable worldwide.
- Nuclear facilities are vulnerable to terroristic attacks. Severe accidents could also be initiated by hostile actions in an armed conflict anywhere in the world. The consequences of a Chernobyl-type accident do not stop at our borders.
- The use of MOX fuel in civil nuclear reactors poses a great risk for terroristic use of plutonium in primitive but effective bombs.

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 amounts of radioactivity are a billionfold of the front end processes. Vulnerable in particular are all facilities containing spent nuclear fuel: reactors, spent fuel interim storage facilities and reprocessing plants. Because of the very long storage periods (could come to 100 years or more) of the radioactive wastes in temporary storage facilities the inevitable ageing of materials is of major concern, a concern excerbated by economic factors (see below). On top of these factors the interim 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 affect vast regions. Radioactive dust from uranium mines, containing extremely hazardous radionuclides, is blown by the wind over distances of thousands of kilometers in arid areas, for example in Australia, Namibia, USA.

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 the reprocessing plant.

The pathways of tritium and carbon-14 into the human body via drinking water and the food chain are briefly discussed in this study. The long-term health effects of these two biochemically very active radionuclides in the human body are not well understood. Both tritium and carbon-14 are released on daily routine basis in large quantities by nuclear power plants, spent fuel storage facilities and reprocessing plants, under nominal operating conditions.

**Second Law**

The Second Law of thermodynamics plays a vital role with regard to nuclear safety and for that reason it is briefly introduced in this study. As a consequence of the Second Law materials, structures and equipment are degrading by time. Maintenance can retard the spontaneous degrading processes, but cannot prevent them.
Another consequence of the Second Law is that the separation of a mixture of chemical species into pure fractions never goes to completion. Unavoidably a fraction of the species in a mixture will be lost in the waste streams of any separation process. The separation yield declines with:

- increasing number of species in the mixture
- decreasing concentration of the wished for species in the mixture
- increasing chemical and physical similarity of the species to separate.

The Second Law also implies, among other, that materials and structures cannot be made 100% perfect and reliable. This conclusion in turn has important consequences for the technical feasibility of some advanced technical concepts.

These observations are ignored in the communication of the nuclear industry to the general public and politicians, in its reassuring statements on safety and in its presention of advanced technological concepts as mature techniques, some of which turn out to be possible only in cyberspace.

**Nuclear safety**

The nuclear industry claims nuclear power to be safe and clean, refering to a limited number of probabilistic risk analyses (PRAs) of Western types of nuclear reactors. This claim has a flawed basis for several reasons:

- The official safety studies of the nuclear industry are covering a very limited portion of all industrial activities constituting the nuclear process chain from cradle to grave.
- The probabilistic safety analyses done by the nuclear industry cover a limited number of types of nuclear reactors, comprising a small part of the existing nuclear installations worldwide which have the potential of large-scale accidents.
- PRAs cover only mechanical failures of a system and are based on the assumption that materials and stuctures are of design quality. Ageing of materials and of electronics (a consequence of the Second Law) is hardly to quantify in the models. Preflight testing of complete systems, a common practice in aerospace technology, is lacking in nuclear technology.
- A number of unavoidable and unpredictable factors cannot be quantified, such as:
  - human behaviour
  - economic pressure
  - terrorism
  - accidents by external causes
  - natural disasters

According to the official safety analyses the chance of a 'major accident' (the nuclear jargon for a Chernobyl-like disaster) is once every 2500 years worldwide. Practice proves that chance to be about once every 10-20 years.

A number of risk enhancing factors are discussed in this study, some technical, other non-technical. The chances of nuclear accidents and the magnitude of the imposed health risks increase with time fora number of reasons, such as:

- rapidly increasing amounts of human-made radioactive materials in mobile state
- unavoidable degradation of materials and constructions
- increasing economic pressure.

Inherently safe nuclear power is inherently impossible. In nuclear technology, as in any technology, only engineered safety exists, which is subject to ageing, to economic pressure and to unpredictable human behaviour.
Substantial dedicated human effort and large investments of materials and useful energy can reduce the chance of large-scale dispersion of anthropogenic radioactivity into the human environment, but cannot eliminate it, as history has shown.

Health risks of nuclear power are exacerbated by the fact that a number of routinely discharged hazardous radionuclides are difficult to detect, such as tritium, carbon-14 and iodine-129. But also numerous other hazardous alpha-emitting radionuclides in scrap and debris, originating from dismantled nuclear installations, including some actinides, are hard to detect by commonly used radiation detectors and so these radionuclides can easily enter the public domain, unnoticed.

Large-scale accidents, involving dispersion of thousands of nuclear bomb equivalents of radioactivity, remain possible. Fukushima will not be the last one if the current paradigm of living on credit in the nuclear world persists.

### Factors enhancing nuclear health risks

The chances of contracting a radiation-induced disease, either lethal or non-lethal, resulting from contamination with radioactive substances are enhanced by several factors.

One factor is the fact that a number of biologically very active (and dangerous) radionuclides are not detectable by means of commonly used radiation detectors. So it is possible that large numbers of people are contaminated by significant doases of radioactivity without knowing it, and without acknowledgement by the nuclear industry, greatly enhancing insidious health risks. Several studies proved this effect to exist.

Health risks posed by nuclear power are increasing with time due to several time-dependent phenomena, for example:

- Increasing amounts of mobile radioactive material piling up in an increasing number of temporary storage facilities.
- Unavoidable deterioration of materials and structures of spent fuel elements and of temporary storage facilities of radioactive wastes, due to degrading mechanisms as a consequence of the Second Law of thermodynamics.
- Increasing economic pressure, resulting in:
  - decrease of safety-related investments and staff at the nuclear power plants
  - relaxation of official exposure standards and regulations
  - decrease of the efficiency and independency of inspections.
- Increasing probability of terroristic and war actions,
- Increasing threat posed by illegal trade of radioactive materials.

### Reliance on models in the nuclear industry

The official radiation exposure standards for individuals are based on computer models, starting from unclear axioms and assumptions, which are not widely understood by scientists outside of the nuclear world, let alone by the public and politicians. The models are based on direct exposure to radiation from extern radiation sources and originate mainly from the 1940s and 1950s.
Any mathematical and physical model has its inherent limitations and specific limitations and may exhibit considerable built-in uncertainties. Therefore they are not rock-solid. Extensive studies proved the official models to be unable to explain observed radiation-induced diseases and deaths. Apparently the models are not validated using empirical evidence from the past decades.

Likely the radiological models do not include factors such as:

- Biochemical properties of radionuclides within the living cells, after inhalation and/or ingestion of radioactive materials via air, water and/or food.
- Non-targeted and delayed effects.
- Chronic exposure to low doses of a number of different radionuclides simultaneously.

- Synergestic effects.

**Nuclear health risks and economics**

*Après nous le déluge*
The nuclear industry has a habit of *Après nous le déluge* by postponing indefinitively the actions required to deal adequately with the human-made radioactivity. The assertion of the World Nuclear Association, representing the Western nuclear industy, that all safety matters are fully under control is in flagrant contradiction to the practice.
Strong economic and financial forces dominate the views in the political and industrial domains with regard to nuclear power and the perception of its health risks.

*Energy debt*
Nuclear power is building up immense energy debts by postponing the immobilisation and isolation of the radioactive waste from the biosphere, which is the only way to prevent large-scale accidents affecting vast regions. A physical analysis of the activities required to finish the overdue cleanup of the nuclear heritage points to the consumption of massive amounts of energy, materials and human resources and consequently to unprecedented economic efforts.

The energy debt has a physical basis and will grow with time due to unavoidable deterioration of materials and structures with time, even if no new human-made radioactivity would be added to the existing amounts. The energy debt is not depreciating with time and cannot be discounted nor written off like common monetary debts. The financial consequences of the nuclear debts in countries like France and the UK are estimated to rise to hundreds of billions of euros, several times the final cost of the entire US Apollo moon project, with its huge technological spinoff. With the Apollo project six crews succesfully landed on the Moon and returned safely to the home planet.

Redeeming the energy debt will become increasingly burdensome to the economic system in the future, due to a forgotten trend: the increase of the thermodynamic scarcity of vital minerals. With time the amount of energy required to extract one kilogram of a metal or other mineral from the Earth's crust will increase, due to the declining quality of the yet-to-exploit ores. The richest available resources are always exploited first.

We may wonder if the future generations will be able to solve the problem we could not. Would the future generations have to their disposal sufficient energy, materials, human resources (skilled workforce) and economic 'ability to cope' to make their living environment as save as we and they would wish?

*Externalisation of costs*
Liability and cost of the back end of the nuclear process chain is systematically passed on to the taxpayer by the nuclear industry.
Delayed expenses, for example definitive waste storage and dismantling of nuclear power stations, are systematically passed on to the future and consequently to the taxpayer: privatising the profits, socialising the costs.
Discussions on lifetime costs, based on empirical data and not on wishful thinking, are the only method for a fair comparison of different energy supply systems, for example nuclear power

with renewables.

*Relaxation of standards*
De-regulation of electricity markets has pushed nuclear utilities to decrease safety-related investments and to limit staff.
The official standards for discharge of radioactive substances into the environment are susceptible to economic pressure. Relaxation of the standards of emissions occurs on grounds of economic arguments, not on grounds of scientific evidence. The same holds true for the classification of radioactive materials: either for unrestricted use in the public domain or as radioactive waste. Here the use of computer models happens to be convenient: models can easily be adapted, empirical evidence not.

The efficiency and the independency of inspections of nuclear activities are under high economic pressure. The frequency of inspections is lowered to save costs. The nuclear industry urges for simplified and shortened license procedures with elimination of participation of local authorities. independent institutions and the public.

**Communication**

Communication to politicians and the public on nuclear affairs is complicated by a number of factors, such as:
- complexity of the nuclear energy system as a technical system and consequently its opacity
- military connection of nuclear technology
- secrecy
- political interests
- financial interests

*Entanglement of interests*
Information on nuclear matters to the public and politicians originates almost exclusively from institutions with vested interests in nuclear power, for example International Atomic Energy Agency (IAEA), World Nuclear Association (WNA), Nuclear Energy Agency (NEA), Nuclear Energy Institute (NEI), and from the nuclear industry itself, e.g. Areva and Electricité de France (EdF).

The authoritive 'nuclear watchdog' International Atomic Energy Agency (IAEA) has the promotion of nuclear power in its mission statement. Moreover, official publications of the IAEA have to be approved by all member states of the IAEA.
The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP) have strong connections with the IAEA.
The World Health Organization (WHO) cannot operate independently of the IAEA on nuclear matters.

*Questionable scientific methods*
The IAEA, and with it the nuclear industry, counts only persons suffering from deterministic effects of radioactivity, that are the acute deaths, as victims of nuclear accidents, for example Chernobyl.

Wide disparities exist with regard to stochastic health effects of exposure to radioactive materials. The nuclear industry, especially the IAEA, pay little or no attention to publications from outside of the nuclear world, based on empirical evidence and pointing to connections between adverse health effects and radioactivity, which do not fit the views of offical publications. The IAEA does not bother to discuss in a scientific way the differences with their own studies and seems to take the view:

"We do not need to look at it, because it cannot be true according to our models."

Unusual scientific methods are noticeable in reports of the nuclear watchdog IAEA on the Chernobyl disaster:

- reversed argumentation: the models are correct, empirical observations incompatible with the models are wrong *because* they are incompatible,
- biased database: ignorance of data which do not fit in the official paradigm,
- missing proofs: postulation of a theory to explain observed phenomena without underpinning the theory with unambiguous proofs,
- absence of falsification of other theories which could explain observed phenomena as well, or even better, than the reported explanations.

*Downplaying the hazards*

Downplaying the risks and health effects of radioactivity is an invariable constituent of the official statements from the nuclear world, regarding accidents and routine releases involving radioactive materials.

Systematic minimalisation of the health effects caussed by radioactivity in the human body is linked to:

- the long latency periods and the stochastic occurrence of the (always detrimental) health effects
- many unknowns with regard to the biochemical mechanisms of radionuclides inside the human body
- reliance on models and ignorance of empirical evidence.

By its unusual scientific methods and by systematically playing down the health risks of radioactivity the nuclear world has developed a strongly biased way to communicate with the general public and politicians on matters of health effects and risks of nuclear power.

By denying the long-term adverse health effects of radioactivity much help for the affected people may remain undone. Down playing the hazards does not mitigate the adverse health effects resulting from radioactive contamination.

it happened in Ukraine, Belarus and Russia after the Chernobyl disaster, it threatens again to happen in Japan after the Fukushima disaster.

# Main conclusions

- Adverse health effects of radioactivity in the human body are far more serious and are inflicted at far lower doses of radioactive contamination than the official models predict.
- Mechanisms of the biochemical effects of radiation and radionuclides inside of the human body are poorly investigated and largely unknown. A number of observed phenomena are not understood.
- Inherently safe nuclear power is inherently impossible.
  As with any technical system, only engineered safety is possible, which is subject to:
  - degrading mechanisms as a consequence of the Second Law of thermodynamics
  - degrading effects resulting from economic pressure,
  - unpredictable human behaviour,
  - unpredictable natural disasters
- Nuclear power delivers energy on credit. All radioactive waste ever generated is still stored in temporary storage facilities, increasingly vulnerable to accidents. Safe isolation and storage of the nuclear heritage constitutes a huge debt in terms of energy, materials, human effort and economic means.
- Safe solution of the nuclear waste problem is not a matter of advanced technology, it is a matter of dedicated effort.
- The communication on nuclear matters from the nuclear industry, IAEA and WHO to politicians and the general public is one-sided, coloured by conflicts of interests and flawed by questionable scientific methods.
- The official views of the nuclear industry and its associated institutions on nuclear health risks heavily rely on computer models most of which stem from the 1940s and 1950s.
- Health hazards posed by nuclear power are systematically downplayed by the nuclear industry.
- Dispersion of radioactive materials into the human environment is increasing with time and consequently the insidious health risks of radioactive contamination.
- The chance of another disaster like Chernobyl and Fukushima is increasing with time.
- Health risks posed by nuclear power seem to be in the first place an economic notion. Economic and financial considerations strongly affect the safety culture in the nuclear industry. Safety standards, based on computer models, can easily be adapted to economic choices.

# Epilogue

Nuclear power covered 2,9% of the world final energy consumption in 2010, corresponding with 1.9% of the world primary energy production, a share declining with time. The Chernobyl and Fukushima disasters each caused an economic damage of hundreds of billions of dollars and affected the health of millions of people. If we continue with nuclear power in the 'business-as-usual' mode, Fukushima might be not the last disaster of its class
Thinking about nuclear power homo economicus should wonder:

*How much health damage and how much economic damage are we willing to accept in exchange for that small nuclear contribution?*

*For what reason do we think society needs nuclear power? Aren't there other ways to make huge profits, in much safer, cleaner and affordable ways, which are really sustainable?*

*How much are we willing to pay for the health and socio-economic stability of ourselves, our childern and grandchildern and their offspring?*