Problems for the future
- message to the future

Jan Willem Storm van Leeuwen
Independent consultant

member of the Nuclear Consulting Group

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storm@ceedata.nl

Note
In this document the references are coded by Q-numbers (e.g. Q6). Each reference has a unique number in this coding system, which is consistently used throughout all publications by the author. In the list at the back of the document the references are sorted by Q-number. The resulting sequence is not necessarily the same order in which the references appear in the text.

Contents

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, resulting in larger risks of radioactive contamination
- 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 debt, latent entropy

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 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?

Message to the future.

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] Q646. 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] Q421 are not encouraging, as little as the cost estimates of the cleanup of the Hanford Site in the USA [DOERL 2015] Q653. 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.

Heading for future disasters

Economic impact of the Chernobyl disaster

The economic damage and losses of the Chernobyl disaster are not easily to define or assess. According to the [Chernobyl Forum 2008] Q497 the total cost in Belarus over 30 years is estimated at US$235 billion (in 2005 dollars). In its report the Chernobyl Forum stated that between 5% and 7% of government spending in Ukraine still related to Chernobyl, while in Belarus over $13bn is thought to have been spent between 1991 and 2003, with 22% of national budget having been Chernobyl-related in 1991, falling to 6% by 2002. Much of the current cost is related to the payment of Chernobyl-related social benefits to some 7 million people across the three countries.
A significant economic impact at the time was the removal of 784,320 ha of agricultural land and 694,200 ha of forest from production. While much of this has been returned to use, agricultural production costs have risen due to the need for special cultivation techniques, fertilizers and additives. The costs of dismantling and cleanup of the Chernobyl site are not included in above estimates.

Economic impact of the Fukushima disaster

Obviously the socio-economic impact of the Fukushima disaster is extensive. Many tens of thousands of people have been evacuated from their homes, without any prospect of a safe return. Various effects of Fukushima are discussed by [Dorfman et al. 2013] Q288.
Liabilities and compensation claims of the disaster might be measured in hundreds of billions of euros. The cleanup of the site is preliminarily estimated at some €250bn [NDreport 2011] Q524. One may wonder if these extreme costs will counterbalance the benefits of nuclear power. Fukushima might be not the last nuclear disaster of its class.

Economic burden

As a result of its *après nous le déluge* attitude the nuclear world is building up an economic challenge of unprecedented size. At some moment the reprocessing plants at Sellafield and La Hague – limiting the scope to the European situation – have to be decommissioned and dismantled. These activities might cost many 100s of billions of euros and will require massive efforts over decades, as pointed out above. The investments are increasing with time due to an increasing contamination of the buildings and constructions with all kinds of radionuclides from spent fuel. Also if the reprocessing plants closed down today, the dismantling investments would still increase over time, due to the unavoidable and progressive degrading processes of the materials and constructions and other causes mentioned above.
Even in times of a booming economy dismantling and site cleanup of a reprocessing plant would be a highly demanding task. What about the prospects in a declining economy?
In addition to the reprocessing plants, all presently operating nuclear power stations are to be decommissioned and dismantled someday. Preliminary indications point to costs of one to two times the construction cost for each reactor.

Après nous le déluge

Any country with an appreciable number of nuclear power plants, such as France, Great Brittain and the United States, should reckon on economic efforts of Apollo project size, many hundreds of billions of euros, to keep their territory (and of the neighboring countries) habitable. Would the decision makers foster such efforts, or does the world need another Chernobyl/Fukushima disaster? That may happen in Europe or in the USA. The current way of economic thinking, pursuing only short-term profit goals, is not reassuring in this respect.

With respect to radioactive waste problems and health risks the nuclear world seems to foster a culture of downplaying and concealing risks combined with an unrealistic belief in unproved and unfeasible technical concepts. This paradigm is exacerbated by a chronic habitus of living on credit that may be best described as an *après nous le déluge* attitude, which seems to be based on questionable arguments and fallacies, such as:

> Technology advances with time and future generations will be richer than our generation, so they will have more economic means and better technological possibilities at their disposal to handle the waste problem.

Or, as John Broome put it [Broome 2008] Q424:

> How should we – all of us living today – evaluate the well-being of future generations, given that they are likely to have more material goods than we do?

A nuclear disaster cannot be prevented by denying its breeding ground.

View of the nuclear industry

The World Nuclear Association (WNA) states [WNA 2016a] Q540 and [WNA2012b] Q541:

> Nuclear power is the only energy industry which takes full responsibility for all its wastes, and costs this into the product.

This WNA statement is, if not a lie, in sharp conflict with the evidence of the energy debt and empirical facts encountered in this study and also with the observations such as:

- In the USA the federal government is responsible for the final storage of the spent fuel in a geological repository. Because of this, by definition the American taxpayer bears financial liability for the decommissioning and dismantling of the nuclear power plants.
- In the UK the shut down nuclear power plants are sold for a symbolic amount to the government, which then takes on the responsibility of the cleanup, decommissioning and dismantling of the discarded radioactive facilities. In this case it's likely the British taxpayer also has to pay for the construction of a geologic repository plus the packaging and definitive sequestration of the nuclear waste.
- In France a different situation exists. Nuclear activities in France are managed by two state-owned companies: Areva and Electricité de France (EdF). Who pays the bill?
- In the Netherlands the State has the full financial responsibility for the management of radioactive waste [OECD-NEA 2005] Q502.

What is the situation in other countries, for example Russia, China, India, South Korea, Japan?

Questionable assumptions

Radioactive wastes from dismantling nuclear power plants and reprocessing plants are missing from the waste management scenarios published by the nuclear industry, despite the tremendous volumes to be expected, counted in hundreds of thousands, may be millions of cubic meters, the astronomical costs and the imperfectly known radioisotopic composition of this waste.

The nuclear industry sharply distinguishes spent fuel and high-level waste from other radioactive wastes, suggesting that those other wastes are not dangerous. Although the specific activities of 'low level' waste are orders of magnitude lower than of spent fuel and other high-level wastes, the volumes are many orders of magnitude larger and are dispersed over more storage facilities. Consequently the chances for individuals to contract a hazardous or lethal dose by exposure to lower level radioactive materials are accordingly greater, the more so because the safeguards of the 'not-to-worry-about' wastes are substantially less stringent than of spent fuel and other high-level wastes, in some cases nonexistent.

'Low level' waste can contain extremely hazardous radionuclides, such as actinides, albeit at relatively low concentrations. An added complication is that the distincion between low and high level generally is made by measuring the gamma radiation at the outside of the waste container. Dangerous radionuclides emitting no or weak gamma radiation are not detected by the detectors. If a container should leak the dangerous, invisible radionuclides get dispersed into the human environment.

The distinction between 'low level' and 'high level' obviously has economic roots, for the final disposal options as envisioned by the nuclear industry for the 'not-to-worry-about' wastes, shallow burial and/or above-ground storage for 'only' four to ten centuries, are much cheaper than a deep geologic repository. How sure can we be of the integrity of a human construction after 400-1000 years, looking back in history to the years 1600 or 1000?

Apparently the nuclear industry bases its proposed solutions of radioactive waste management issues – they emphatically deny there is a waste *problem* – on questionable assumptions, among others:

- The assumption that future generations will keep the knowledge of the exact locations and properties of the stored 'not-to-worry-about' radioactive wastes generated centuries ago and will have the expertise and economic means to maintain the storage facilities in a proper state and to safely handle the wastes in case of unexpected events, such as earthquakes, floods and wars.

- The assumption that future generations will have the political drive and sufficient economic means and skilled workforces at their disposal to perform the demanding tasks our generation could not handle.

Hazards

The amount of man-made radioactivity generated by a reactor is a billion times the radioactivity of the fresh uranium entering the reactor. One reactor of 1 GWe generates as much radioactivity as 1000 exploded nuclear bombs of about 15 kilotonnes, the yield of the Hiroshima bomb, each year. The radioactivity is in physically and chemically mobile form present in the nuclear chain and consequently in the human environment. Roughly 90-95% of the radioactivity is contained in spent fuel (if not reprocessed), the other 5-10% is dispersed over massive volumes of materials, such as construction materials and chemicals.

What is known about chronic exposure to 'low' doses of radionuclides entering the body via inhalation of gases and aerosols and ingestion via drinking water and food? Exposure to radioactive materials implies more than exposure to radiation. Radiological models are based on radiation and do not include the biochemical behaviour of radionuclides inside the human body, such as accumulation in specific organs. Weak radiation emitters, for example tritium, might be very dangerous in unshielded living cells in the body. The effects could be exacerbated in the case of chronic exposure of people living in contaminated areas.
Nothing is known about exposure to a mix of different radionuclides. The published reports on childhood cancers in the vicinity of nuclear power plants (see for example [KiKK 2007] Q392and [Geocap 2012] Q494) and on the consequences of the Chernobyl and Fukushima disasters [IPPNW 2011] Q452 are far from reassuring with respect to health hazards posed by radioactive materials.

Realization of the nuclear scenarios combined with the currently prevailing après nous le déluge culture of the nuclear industry would greatly enhance health hazards and risks of accidents and terrorism. We can expect increased dispersion of radioactive materials into the environment due to the unavoidable and progressive deterioration of the materials enclosing the radioactive wastes of the nuclear chain, combined with increasing amounts of radioactive waste, stored at an increasing number of temporary storage facilities. Other risks are posed by the ever increasing number of waste transports of radioactive materials.
The risks of severe accidents like Chernobyl and Fukushima will increase due to the increasing number of nuclear power plants and spent fuel cooling pools, this in combination with the progressive ageing of nuclear power plants and reprocessing plants.
If the reprocessing of spent fuel were to be continued in the future the risks of nuclear terrorism would grow day by day, because an increasing amount of plutonium and other fissile materials would be transported and stored at different places.
As a result of the living-on-credit culture prevailing in the nuclear industry, all human-made radioactivity ever generated is still stored in makeshift facilities, if not already dumped into the sea, lakes, rivers or landfills. Not one uranium mine in the world has been properly rehabilitated after depletion of the ore deposit. Isolation from the biosphere of all radioactive materials in the least risky way is a *conditio sine qua non* to secure our children, grandchildren and future generations against the insidious hazards of the tremendous quantities of human-made radioactivity, the latent entropy.
Based on the above observations this study started from the viewpoint that all radioactive wastes from nuclear power have to be definitively isolated from the biosphere as securely and as soon as possible after generation of the radioactive waste, to minimize discharges of radioactivity into the human environment and to minimize the risks of accidents and large disasters. Prevention of radioactive contamination and accompanying health hazards is not possible, just a minimalization of the hazards.

Economic preferences and nuclear safety

Economic preferences and commercial choices can greatly increase nuclear security risks. There is the relaxation of the official standards for operational routine discharges of radionuclides into the environment by nuclear power plants and reprocessing plants. Due to ageing the frequency of leaks and spills will rise at an accelerating rate and so will the costs to repair the leaks and to prevent their occurrence. Raising allowable radioactive discharge limits for the nuclear operators keeps their costs down, while resulting in higher exposure standards for the general public, often by large factors, without scientific justification. Similar relaxation of exposure standards may be expected in the case of future nuclear accidents, as occurred after the Fukushima disaster. Another example is the relaxation of standards for clearance of radioactive construction materials for unrestricted use in the public domain. This might become a hot issue when heavily contaminated nuclear installations would be dismantled; safe guardianship and disposal of the massive amounts of radioactive debris and scrap might be very expensive.
Economic reasons can push the trend of lifetime extension for nuclear power stations beyond the designed lifetime of 40 years. It is not clear how the owners of the plants and the supervisory institutes incorporate the unavoidable ageing and the bathtub function in their security assessments, or how independent or how thorough the inspections are.

The risks for catastrophic breakdown of technical devices, including nuclear reactors, increase as the devices age, much like the risks for death by accident and illness change as people get older. There are three distinct stages in the lifetime of any technical system or living organism:

- the break-in phase, also called the burn-in phase or the infant mortality phase,
- the middle life phase, also called the useful life,
- the wear-out phase.

The risk profile, the failure rate as a function of time, is called the bathtub hazard curve for it curves like a bathtub. The bathtub curve is drawn from statistical data about lifetimes of both living and nonliving things, such as cars, cats or nuclear reactors [Sheldon 2009] Q165, [Stancliff et al. 2006] Q433.

Another cause for concern is illegal trade and smuggling of nuclear materials, often high-grade and expensive, only a small step from nuclear criminality and terrorism. Transports of hazardous materials are difficult to detect, if detection is possible at all. This problem increases with time due to increasing amounts of radioactive materials and declining inspections. One of the consequences is the uncontrolled release of radioactive materials into the public domain and insidious exposure of a growing number of people to radionuclides. Serious accidents and terroristic actions cannot be ruled out. Political instability, for whatever reason, exaggerates the risks of illicit nuclear transports with malicious intent.

Downplaying and denial of health effects, conflict of interests

Communication between the nuclear industry and the national governments is dominated by the IAEA. 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. Moreover, official publications of the IAEA have to be approved by all member states of the IAEA. For these reasons the IAEA cannot be regarded as an independent scientific institute. No agency can be a true watchdog for an industry it is tasked with promoting. Political and economic interests may play a role in the decision processes concerning nuclear issues.
Two other international nuclear-related institutes, the International Commission on Radiological Protection (ICRP) and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have strong connections with the IAEA.

The World Health Organization (WHO) also reports on the health aspects of nuclear power, especially in case of large accidents (Chernobyl, Fukushima). Although the WHO is an independent UN organization, its reports on nuclear matters are subject to IAEA's approval. 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, see also [Tickell 2009] Q527, [WHO 2009] Q562, [Sinaï 2013] Q526 and the preface of [WHO 2013a] Q553. The IAEA ranks higher in the UN hierarchy than the WHO.
Concerning health effects of radioactivity the IAEA, ICRP, UNSCEAR and WHO speak with one voice.

From the reports of the IAEA, UNSCEAR and WHO on the subject of health effects, especially concerning the disasters of Chernobyl and Fukushima, emerges a picture of the nuclear world marked by *downplaying* and even *denial of health effects* caused by exposure to radiation and radioactive materials.
Non-cancerous diseases are not recognized as radiation-induced health effects, attention is paid only to acute radiation syndrome (ARS, radiation sickness).
The IAEA and the nuclear industry place full reliance on models from the 1940s and 1950s for estimation exposure to radiation (that is not the same as exposure to radionuclides) and the dosis-effect relation. In addition the models have a limited scope and empirical evidence of the past several decades is not included in the models. The evidence presented in the KiKK, GeoCap and IPPNW studies mentioned above cannot be explained by the radiological models; as a matter of fact these studies are not even mentioned in the official publications of the IAEA and nuclear industry.
Biochemical behaviour of radionuclides inside human body is not included. Chronic exposure to a mix of different radionuclides inside the body, via ingestion (food and water) and inhalation (gases, dust) are also not covered. The radiological models applied by the IAEA and nuclear industry turn out to be easily adaptable to economic and financial considerations at a given moment, as became evident after the Fukushima disaster.

Reliable investigations of the health effects of the Chernobyl and Fukushima disasters are hampered by several factors, such as:
- poor detectability of many dangerous radionuclides with handheld radiation counters
- long latency period of health effects from exposure to radioactivity, coupled with a short time horizon of the investigations
- limited measurements of radioactive contamination
- limited scope of the IAEA and WHO investigations
- absence of solid statistical databases and absence of adequate epidemiological studies
- secrecy of medical data.

There no reasons to expect that this would be better during the next disaster.

The IAEA reports are committing elementary scientific flaws in downplaying and even denial of health effects caused by exposure to radioactivity and radioactive materials, externally and inside the body. Examples of questionable methods are:
- Presentation of 'definitive answers' on the consequences of the Chernobyl disaster [WHO 2005] Q498
- Ignoring studies with diverging results, see e.g. IPPNW 2011] Q452
- Missing proofs, see e.g. IPPNW 2011] Q452
- Models prevailing over empirical evidence, [WHO 2005] Q498, [Chernobyl Forum 2006] Q497
- Absence of a scientific discourse, absence of a dialogue, for example concerning the studies [KiKK 2007] Q392, [GeoCap 2012] Q494, [Mousseau et al. 2013] Q615
- Downplaying critiques to 'ignorance' and 'fear of the unknown'.

A downplaying trend becomes clear in the IAEA/UNSCEAR/WHO reports concerning the disasters of Chernobyl and Fukushima, see for instance the following studies and reports:
[UNSCEAR 2013b] Q573,
[UNSCEAR 2011] Q571,
[TORCH 2006] Q521,
[Greenpeace 2006] Q514,
[Yablokov *et al*. 2009] Q419,
[UCS 2011] Q522,
[Yablokov 2011] Q565,
[Chernobyl Forum 2006] Q497,
[IPPNW 2011] Q452,
[IPPNW 2013] Q574,
[WNA-*chern* 2016] Q727,
[Paulitz 2012] Q559,
[Rosen 2012b] Q560,
[WHO 2011a] Q570,
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This issue is further addressed in report m05 *Downplaying and denial of health effects*.

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