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Editorial

Dear readers of the WISE/NIRS Nuclear Monitor,

In this issue of the Monitor, two detailed articles on issues relevant to the upcoming U.N. COP21 climate conference in Paris:

- Nuclear Monitor editor Jim Green deconstructs climate scientist James Hansen's nuclear fantasies.
- Jan Willem Storm van Leeuwen analyses the (limited) potential for nuclear power to slow down climate change.
- And we have a short item about the provocative Dutch artist TINKEBELL.

Feel free to contact us if you have feedback on this issue of the Monitor, or if there are topics you would like to see covered in future issues.

Regards from the editorial team.

Email: monitor@wiseinternational.org

Monitored this issue:

James Hansen's nuclear fantasies

Author: *Jim Green − Nuclear Monitor editor*

NM814.4513 Climate scientist James Hansen will be promoting nuclear power − and attacking environmental and anti-nuclear groups − in the lead-up to the U.N. COP21 climate conference in Paris in December.[1] The press release announcing Hansen's visit to Paris berates environmentalists for failing to support "safe and environmentally-friendly nuclear power". The press release notes that the Climate Action Network, representing all the major environmental groups, opposes nuclear power − in other words, efforts by nuclear lobbyists to split the environment movement have failed.

Hansen won't be participating in any debates against nuclear critics. His reluctance to debate may stem from his participation in a 2010 debate in Melbourne, Australia.[2] The audience of 1200 people were polled before and after the debate. The pre-debate poll found an 8% margin in favour of nuclear power; the post-debate poll found a margin of 24% against nuclear power. The turn-around was so striking that Hansen's friend and colleague Barry Brook falsely claimed the vote must have been rigged by anti-nuclear and climate action groups. "I can think of no other logical explanation – statistically, such a result would be nigh impossible," Brook claimed.[3]

Nuclear safety

An article co-authored by Hansen and Pushker Kharecha, published in the *Environment, Science and Technology* journal, claims that between 1971 and 2009, "global nuclear power has prevented an average of 1.84 million air pollution-related deaths and 64 gigatonnes of CO2-equivalent greenhouse gas emissions that would have resulted from fossil fuel burning".[4] They also calculate that "nuclear power could additionally prevent an average of 420 000–7.04 million deaths and 80–240 GtCO2-eq [equivalent gigatons of carbon dioxide] emissions due to fossil fuels by midcentury, depending on which fuel it replaces [gas or coal]".

Kharecha and Hansen ignore the potential of renewables and energy efficiency and conservation. Instead they set up a false choice between fossil fuels and nuclear. Even as an assessment of the relative risks of nuclear and fossil fuels, the article doesn't stack up.

Kharecha and Hansen claim that 4,900 deaths have resulted from nuclear power between 1971 and 2009. They continue: "[E]mpirical evidence indicates that the April 1986 Chernobyl accident was the world's only source of fatalities from nuclear power plant radiation fallout." Why narrow the focus from the full energy cycle to power plants? Why limit consideration of fatalities to radiation fallout alone? There have been countless fatal accidents at nuclear fuel cycle facilities.[5]

Kharecha and Hansen cite the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) to justify their figure of 43 deaths from the Chernobyl disaster.[6] But the UNSCEAR report did not attempt to calculate long-term deaths from radiation exposure from Chernobyl, citing "unacceptable uncertainties in the predictions". The credible estimates of the long-term cancer death toll from Chernobyl range from 9,000 (in Eastern Europe) to 93,000 (across Eastern and Western Europe).[7]

Hansen states: "No people died at Fukushima because of the nuclear technology." The real impacts of the disaster are summarised by radiation biologist Dr Ian Fairlie:[8]

"In sum, the health toll from the Fukushima nuclear disaster is horrendous. At the minimum:

- *Over 160,000 people were evacuated, most of them permanently.*
- *Many cases of post-trauma stress disorder (PTSD), depression, and anxiety disorders arising from the evacuations.*
- *About 12,000 workers exposed to high levels of radiation, some up to 250 mSv*
- *An estimated 5,000 fatal cancers from radiation exposures in future.[9]*
- *Plus similar (unquantified) numbers of radiogenic strokes, CVS diseases and hereditary diseases.*
- *Between 2011 and 2015, about 2,000 deaths from radiation-related evacuations due to ill-health and suicides.*
- *An, as yet, unquantified number of thyroid cancers.*
- *An increased infant mortality rate in 2012 and a decreased number of live births in December 2011."*

Regarding Fukushima, Kharecha and Hansen state that "one early analysis indicates that annual radiation doses in nearby areas were much lower than the generally accepted 100 millisievert threshold for fatal disease development." In defence of the claim regarding a 100 mSv threshold, they cite (and misrepresent) an UNSCEAR report. The UNSCEAR report[10] claims that no studies provide conclusive evidence of carcinogenic effects of radiation at levels below 100 mSv − a claim that is strongly contested.[11]

In any case, UNSCEAR is not claiming that radiation doses below 100 mSv do not cause cancer, but rather that evidence is lacking for such effects. Indeed UNSCEAR's view is that "the current balance of available evidence tends to favour a non-threshold response for the mutational component of radiation-associated cancer induction at low doses and low dose rates."[12] Kharecha and Hansen's assertion regarding a 100 mSv threshold isn't even UNSCEAR's position let alone a "generally accepted" position.

The linear no-threshold (LNT) model of radiation risk "might not be valid for the relatively low radiation doses that the public was exposed to from nuclear power plant accidents," Kharecha and Hansen state. But LNT enjoys some heavy-hitting scientific support. For example the Committee on the Biological Effects of Ionising Radiation (BEIR) of the U.S. National Academy of Sciences states that "the risk of cancer proceeds in a linear fashion at lower doses without a threshold and ... the smallest dose has the potential to cause a small increase in risk to humans."[13]

There is − and will always be − uncertainty regarding LNT. But the uncertainty cuts in both directions: LNT may overestimate or underestimate risks. The BEIR report[13] states that "combined analyses are compatible with a range of possibilities, from a reduction of risk at low doses to risks twice those upon which current radiation protection recommendations are based", and it further states: "Departures from a linear model at low doses, however, could either increase or decrease the risk per unit dose."

Hansen misrepresents relevant scientific institutions (UNSCEAR on the 100 mSv threshold), ignores whatever doesn't suit his pro-nuclear agenda (LNT may overestimate or underestimate risks), and he even gives credence to the discredited view that low-level radiation exposure may be beneficial to human health.[14]

There are many reasons to conclude that Kharecha and Hansen's figure of 4,900 deaths from nuclear power from 1971 to 2009 is a gross underestimate, yet they claim that the figure "could be a major overestimate relative to the empirical value (by two orders of magnitude)".

A realistic assessment of nuclear power fatalities would include:

- **Routine emissions:** UNSCEAR's estimated collective effective dose to the world population over a 50-year period of operation of nuclear power reactors and associated nuclear fuel cycle facilities is two million person-Sieverts.[15] Applying LNT gives a total of 200,000 fatal cancers.
- **Radiation exposure** from accidents, including Chernobyl (estimated 9,000 to 93,000 cancer fatalities) and Fukushima (estimated 5,000 long-term cancer fatalities).
- **Indirect deaths:** In relation to Fukushima, Japanese academics state: "[F]or the Fukushima coastal region, no-one, not even Self-Defense Forces, could enter the area for fear of exposure to radioactive materials, and the victims were left in the area for a long period of time. This resulted in so-called indirect fatalities, people who died due to difficult and long-term evacuation, or those who committed suicide, lamenting the radioactive pollution of their farm lands and farm animals and who had lost hope to ever rebuild their lives. These are considered as fatalities related to the nuclear accident, and their numbers have risen to 1459 as of September 2013, according to the Fukushima Prefectural Office. Though they are considered indirect deaths, they would have not died if there had been no nuclear accident."[16]

Kharecha and Hansen ignore non-fatal impacts. For example, the permanent relocation of 350,000 people in the aftermath of the Chernobyl disaster was associated with a great deal of trauma.[17] Four and a half years after the Fukushima disaster, over 110,000 of the original 160,000 evacuees remain displaced according to the Japanese government.[18] Using those figures (350,000 + 110,000), and the global experience of around 16,000 reactor-years of power reactor operations[19], gives a figure of 29 'nuclear refugees' per reactor-year.

When accidents and routine emissions across the energy chain are considered, renewable energy sources are clearly safer than nuclear power and fossil fuels. Yet Hansen falsely claims that "nuclear power has the best safety record of any energy technology".[14]

Nuclear power is safer than fossil fuels when considering accidents and routine emissions (by a wide margin, though not as wide as Kharecha and Hansen would have you believe) − but then we need to consider the unique WMD proliferation risks associated with the nuclear industry[20] as well as related security issues such as attacks on nuclear facilities.[21]

WMD proliferation

Kharecha and Hansen acknowledge in passing the "potential mortality from proliferation of weapons-grade material", but wave it away on the grounds that it "cannot meaningfully be quantified".

Kharecha and Hansen state: "Serious questions remain about [nuclear] safety, proliferation, and disposal of radioactive waste, which we have discussed in some detail elsewhere." But the paper they cite[22] barely touches upon the proliferation problem and what little it does say is mostly rubbish:

It falsely claims that thorium-based fuel cycles are "inherently proliferation-resistant".[23]

It falsely claims that integral fast reactors (IFRs) "could be inherently free from the risk of proliferation".[24] At best, IFRs could reduce proliferation risks; they could never be "inherently free" from proliferation risks. (Moreover IFR advocates are often disingenuous in their comparisons, for example comparing IFR pyroprocessing favourably against conventional reprocessing (because pyroprocessing does not involve plutonium separation) without considering the once-through no-reprocessing option which compares favourably against both conventional reprocessing and pyroprocessing.)

And Kharecha and Hansen state that if "designed properly", breeder reactors would generate "nothing suitable for weapons". India's Prototype Fast Breeder Reactor will be the next fast reactor to begin operation. It will be ideal for producing weapon grade plutonium for India's weapons program, and it may well be used for that purpose since India is refusing to place it under IAEA safeguards.

Hansen and his colleagues argue that "modern nuclear technology can reduce proliferation risks".[25] But *are* new reactors being made more resistant to weapons proliferation? In a word: No. Fast reactors have been used for weapons production in the past (e.g. by France[26]) and will likely be used for weapons production in future (e.g. by India). Thorium − another 'modern' nuclear technology − has also been used to produce (uranium-233) weapons (e.g. U.S.) and will likely be used for weapons production in future (e.g. India's breeder/thorium program). It is disingenuous − and dangerous − for Hansen to be waving away those realities with claims that "modern nuclear technology can reduce proliferation risks".

Generation IV nuclear technology

Here's Hansen drinking the Kool Aid:[14]

"Nuclear "waste": it is not waste, it is fuel for 4th generation reactors! Current ('slow') nuclear reactors are lightwater reactors that 'burn' less than 1% of the energy in the original uranium ore, leaving a waste pile that is radioactive for more than 10,000 years. The 4th generation reactors can 'burn' this waste, as well as excess nuclear weapons material, leaving a much smaller waste pile with radioactive half-life measured in decades rather than millennia, thus minimizing the nuclear waste problem. The economic value of current nuclear waste, if used as a fuel for 4th generation reactors, is trillions of dollars."

Hansen's views take little or no account of the real-world experience with fast neutron reactors (and Generation IV technology more generally). That real-world experience is littered with accident-prone, obscenely expensive reactors (and R&D programs).[27] Most countries that have invested in fast reactor R&D programs have decided not to throw good money after bad and have abandoned those programs.

Hansen's views are also at odds with reports published this year by the French and U.S. governments. The report by the French Institute for Radiological Protection and Nuclear Safety (IRSN) − a government authority under the Ministries of Defense, the Environment, Industry, Research, and Health − states: "There is still much R&D to be done to develop the Generation IV nuclear reactors, as well as for the fuel cycle and the associated waste management which depends on the system chosen."[28]

IRSN is also sceptical about safety claims: "At the present stage of development, IRSN does not notice evidence that leads to conclude that the systems under review are likely to offer a significantly improved level of safety compared with Generation III reactors, except perhaps for the VHTR [Very High Temperature Reactors] ..." Moreover the VHTR system could bring about significant safety improvements "but only by significantly limiting unit power".

The U.S. Government Accountability Office released a report in July on the status of small modular reactors (SMRs) and other 'advanced' reactor concepts in the US.[29] The report concluded:

"While light water SMRs and advanced reactors may provide some benefits, their development and deployment face a number of challenges. Both SMRs and advanced reactors require additional technical and engineering work to demonstrate reactor safety and economics .... Depending on how they are resolved, these technical challenges may result in higher-cost reactors than anticipated, making them less competitive with large LWRs [light water reactors] or power plants using other fuels. ... Both light water SMRs and

advanced reactors face additional challenges related to the time, cost, and uncertainty associated with developing, certifying or licensing, and deploying new reactor technology, with advanced reactor designs generally facing greater challenges than light water SMR designs. It is a multi-decade process ..."

The glum assessments of the U.S. and French governments are based on real-world experience. But Hansen prefers conspiracy theories to real-world experience, claiming that an IFR R&D program in the U.S. was terminated due to pressure from environmentalists with devious motives: "I think it was because of the influence of the anti-nuclear people who realised that if this newer technology were developed it would mean that we would have an energy source that is practically inexhaustible − it could last for billions of years − and they succeeded in getting the Clinton administration to terminate the R&D for the fourth generation nuclear power plants."

So Hansen lines up with far-right nuts who claim that environmentalists want everyone living in caves. Wrong, stupid, and offensive.[30] No wonder he is having so little success winning over environmentalists.

WMD proliferation was one of the concerns that led to the closure of the IFR R&D program. IFR lobbyists would have you believe that IFRs pose no proliferation risk and that they could help solve proliferation problems by using weapons material (especially plutonium) as reactor fuel. But to quote from an Argonne National Laboratory report (emphasis added): "The reactor ... could be used for excess plutonium consumption *or as a breeder if needed* ..."[31] And Dr George Stanford, who worked on an IFR R&D program in the US, notes that proliferators "could do [with IFRs] what they could do with any other reactor − operate it on a special cycle to produce good quality weapons material."[32]

Renewables and energy efficiency

Hansen states: "Can renewable energies provide all of society's energy needs in the foreseeable future? It is conceivable in a few places, such as New Zealand and Norway. But suggesting that renewables will let us phase rapidly off fossil fuels in the United States, China, India, or the world as a whole is almost the equivalent of believing in the Easter Bunny and Tooth Fairy."[14]

But there are credible studies for the countries that Hansen mentions:

- **USA:** The Nuclear Information & Resource Service maintains a list of reports demonstrating the potential for the U.S. (and Europe) to produce all electricity from renewables.[33]
- **China:** A 2015 report by the China National Renewable Energy Centre finds that China could generate 85% of its electricity and 60% of total energy from renewables by 2050.[34]
- **India:** A detailed 2013 report by WWF-India and The Energy and Resources Institute maps out how India could generate as much as 90% of total primary energy from renewables by 2050.[35]

There is a growing body of research on the potential for renewables to largely or completely supplant fossil fuels for power supply globally.[36]

The doubling of global renewable energy capacity over the past decade has been spectacular[37] with 783 GW of new renewable power generation capacity installed from 2005 to 2014.[38] As of the end of 2014, renewables (including hydro) supplied an estimated 22.8% of global electricity (hydro 16.6% and other renewables 6.2%).[37] Nuclear power's share of 10.8%[39] is less than half of the electricity generation from renewables − and the gap is widening.

The International Energy Agency (IEA) anticipates another 700 GW of new renewable power capacity from 2015−2020.[40] And the IEA report outlines the spectacular cost reductions: the global average costs for onshore wind generation fell by 30% from 2010−2015, and are expected to decline a further 10% by 2020; while utility-scale solar PV fell two-thirds in cost and is expected to decline another 25% by 2020.

There's also the spectacular potential of energy efficiency that Hansen sometimes ignores and sometimes pays lip-service to. A 2011 study by University of Cambridge academics concluded that a whopping 73% of global energy use could be saved by practically achievable energy efficiency and conservation measures.[41] Julian Allwood, one of the authors of the study, said: "We think it's pretty unlikely that we'll find a good response to the threat of global warming on the supply side alone. But if we can make a serious reduction in our demand for energy, then all the options look more realistic."[42]

But let's go with Hansen's argument that renewables and energy efficiency aren't up to the job of completely supplanting fossil fuels. It's not an unreasonable place to go, given that the task is Herculean. What would make nuclear power more palatable? Super-safe, proliferation-resistant Generation IV reactor technology? Not likely.

Improved safety standards and stricter regulation could reduce the risk of catastrophic accidents. A strengthened − and properly funded − safeguards system could reduce the risks of WMD proliferation. And therein lies the greatest irony of Hansen's nuclear advocacy. Many of the environmental and anti-nuclear organisations that he attacks have a long, strong track record of campaigning for improved safety and regulatory standards and for improvements to the safeguards system. Hansen has said little and done less about those issues.

Michael Mariotte from the Nuclear Information & Resource Service neatly sums up the situation: "Dr. Hansen has done the entire world an incredible service with his focus and expertise on climate and his unrelenting warnings that the global community must act to prevent a climate catastrophe. We agree completely. But Dr. Hansen's expertise is climate, not energy. And when he steps in to the energy arena, it becomes clear that his expertise is on climate, not energy."[43]

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   A number of other useful reports are listed at the following webpages:
   http://go100re.net/e-library/studies-and-reports/
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Can nuclear power slow down climate change? An analysis of nuclear greenhouse gas emissions

Author: *Jan Willem Storm van Leeuwen − Ceedata Consultancy*

This is a summary of a November 2015 report commissioned by the World Information Service on Energy (WISE). The full report is posted at www.wiseinternational.org/nuclear-energy/studies-reports

NM814.4514 Nuclear power is claimed to be nearly carbon-free and indispensable for mitigating climate change as a result of anthropogenic emissions of greenhouse gases. Assuming that nuclear power really does not emit carbon dioxide CO2 nor other greenhouse gases (GHGs), how large is the present nuclear mitigation share and how large could it become in the future? Could the term 'indispensable' in this context be quantified? These issues are assessed from a physical point of view, economic aspects are left outside the scope of this assessment.

How large is the present nuclear mitigation share?

The global GHG emissions comprise a number of different gases and sources. Weighted by the global warming potential of the various GHGs 61% of the emissions were caused by CO2 from burning of fossil fuels for energy generation. Nuclear power could displace fossil-fuelled electricity generation, so hypothetically the maximum nuclear mitigation share would be 61% if the global energy supply were to be fully electric and fully nuclear.

In 2014 the nuclear contribution to the global usable energy supply was 1.6% and consequently the nuclear mitigation share was 1.0%.

The International Atomic Energy Agency (IAEA) asserts that the nuclear contribution to the global energy supply was 4.6% in 2014. However, this figure turns out to be based on a thermodynamically inaccurate statistical trick using virtual energy quantities.

How large could the nuclear mitigation to climate change become in the future according to the nuclear industry?

We found no hard figures on this issue, for that reason this study analyses the mitigation consequences of the envisioned developments of global nuclear generating capacity. During the past years the International Atomic Energy Agency and the nuclear industry, represented by the World Nuclear Association (WNA), published numerous scenarios of global nuclear generating capacity in the future, measured in gigawatt-electric GWe. Four recent scenarios are assessed in this study, as these can be considered to be typical of the views within the nuclear industry:

- IAEA low: the global nuclear capacity remains flat at the current level until 2050.
- IAEA high: the global nuclear capacity grows to 964 GWe by 2050, nearly three times the current global capacity of 333 GWe.
- WNA low: the global nuclear capacity grows to 1140 GWe by 2060 and to 2062 GWe by 2100.
- WNA high: the global nuclear capacity grows to 3688 GWe by 2060 and to 11046 GWe by 2100.

The nuclear mitigation share in the four scenarios depends not only on the nuclear generation capacity, but also on the growth rate of the global GHG emissions. The IAEA expects a growth rate of the global energy consumption of 2.0−3.5% per year until 2050. This study assumes that the global GHG emissions will grow during the next decades proportionally to the global energy consumption: also at 2.0−3.5% per year. Based on this assumption – and still assuming nuclear power is free of CO2 and other GHG emissions (which it is not) – the mitigation shares would be as follows, the high figure at a global growth of 2.0%/yr, the low figure at 3.5%/yr:

- IAEA low: 0.5−0.3% by 2050.
- IAEA high: 1.4−0.9% by 2050.
- WNA low: 1.4−0.7% by 2060 and 1.1-0.3% by 2100.
- WNA high: 4.5−2.4% by 2060 and 6.2-1.8% by 2100.

What next after 2050?

The IAEA scenarios are provided through 2050. Evidently the nuclear future does not end in 2050. On the contrary it is highly unlikely that the nuclear industry would build 964 GWe of new nuclear capacity by the year 2050 without solid prospects of operating these units for 40-50 years after 2050.

How does the nuclear industry imagine development after reaching their milestone in 2050? Further growth, leveling off to a constant capacity, or phase-out? Or: let tomorrow take care of itself?

What global construction rates would be required?

By 2060 nearly all currently operating nuclear power plants (NPPs) will be closed down because they will reach the end of their operational lifetime within that timeframe. The current rate of 3−4 GWe per year is too low to keep the global nuclear capacity flat and consequently the global nuclear capacity is declining. To keep the global nuclear capacity at the current level the construction rate would have to be doubled. The average global construction rates that would be required in the industry scenarios are:

- IAEA low: 7-8 GWe per year until 2050.
- IAEA high: 27 GWe/yr until 2050.
- WNA low: 25 GWe/yr until 2060 and 23 GWe/yr from 2060 until 2100.
- WNA high: 82 GWe/yr until 2060 and 184 GWe/yr from 2060 until 2100.

In view of the massive cost overruns and construction delays of new NPPs that have plagued the nuclear industry for decades it is not clear how the required high construction rates could be achieved.

How are the prospects of new advanced nuclear technology?

The nuclear industry promises the application within a few decades of advanced nuclear systems that would enable mankind to use nuclear power for hundreds to thousands of years. This promise concerns two main classes of closed-cycle reactor systems: uranium-based systems and thorium-based systems. For reasons discussed in the detailed version of this report, Uranium-Plutonium as well as Thorium-Uranium breeder concepts turn out to be based on inherently unfeasible assumptions. From this observation it follows that nuclear power in the future would have to rely solely on conventional once-through reactor technology based on natural uranium. As a consequence the size of the uranium resources will be a restricting factor.

How much uranium would be needed to sustain the various scenarios ?

As pointed out above the nuclear generating capacity in the scenarios will not fall to zero at their end date.

The minimum amounts of uranium that would be required in the IAEA scenario's are estimated here by assuming no new NPPs would be build after 2050 and consequently the nuclear power plants operational in 2050 would be phased out by 2100. In case of the WNA scenario's extension after 2100 seemed too speculative. The masses of uranium are given in teragram (Tg): 1 Tg is 1 million metric tonnes.

- IAEA low: 2.3 Tg until 2050 plus 1.7 Tg during phase-out by 2100, total 4.0 Tg uranium
- IAEA high: 4.5 Tg until 2050 plus 4.8 Tg during phase-out by 2100, total 9.3 Tg uranium
- WNA low: 6.6 Tg until 2060 plus 12.7 Tg from 2060 until 2100, total 19.3 Tg uranium
- WNA high: 17.5 Tg until 2060 plus 58.4 Tg from 2060 until 2100, total 75.9 Tg uranium.

Obviously the uranium demand in the IAEA scenarios would be higher if the nuclear capacity were to remain flat after 2050, as opposed to phasing out after 2050 as assumed above; in case of a constant capacity after 2050 the total demand would be about 5.7 Tg in IAEA low and 14.1 Tg in IAEA high.

The known recoverable uranium resources of the world in the cost category of up to 130 USD/kg U amounted to 5.9 Tg in 2013 according to the IAEA; the market price in September 2015 was about 82 USD/kg U. An additional amount of 1.7 Tg of uranium is known to exist in the higher cost category 130-260 USD/kg U.

How are the prospects of the global uranium supply?

Uranium in the earth's crust is unevenly distributed among the rocks comprising the crust. The grade distribution of uranium in uranium-bearing rocks in the earth's crust show a geologic pattern common to other metals: the lower the grade of uranium the larger the amounts of uranium present in the crust. The size distribution of uranium deposits show a similar pattern as a result of the geologic ore-forming mechanisms: the larger the size, the more rare the deposits. From this observation it follows that the chance of discovering new resources increases with lower grades and smaller sizes of the deposits. One may assume that the most easily discoverable resources have been found already and that most easily minable deposits are already being mined. The chances of discovering new large high-grade resources seem low; in reality no such discoveries have been reported during the past two decades.

Based on a simple economic model the nuclear industry states that the global uranium resources are practically inexhaustable, apparently suggesting that any scenario could be materialized. However, the generation of nuclear energy from uranium resources is a physical phenomenon governed by the laws of nature, not by economic notions. The economic model does not include physical and chemical realities with regard to uranium deposits in the earth's crust. Thermodynamics sets the boundaries for the resources that fit the conditions of uranium-for-energy resources.

What are the thermodynamic boundaries of uranium-for-energy resources?

Energy cliff

The energy content of natural uranium that is in any sense extractable is limited: the nuclear power stations that would form the backbone of future nuclear capacity could not fission more than about 0.6% of the nuclei in natural uranium.

The thermodynamic boundaries of the uranium-for-energy resources are determined by the energy required to extract uranium from the resources as found in nature. Analysis of the physical and chemical processes needed to recover uranium from the earth's crust and all the processes needed to release the potential energy in uranium and convert it to useful energy proves that the amount of energy consumed per kg recovered natural uranium rises exponentially with declining ore grades. Below a grade of 200−100 ppm (0.2−0.1 grams U per kg rock) no net energy can be generated by the nuclear system as a whole from a uranium resource, this relationship is called the energy cliff. From this conclusion it follows that only uranium resources at grades higher than 200 ppm (0.2 g U/kg rock) are actually energy sources.

The ore grades of the known uranium resources which are by definition economically recoverable varies widely: from about 200 down to 0.1 gram uranium per kg rock. A part of the resources classified by the IAEA as 'recoverable' falls beyond the thermodynamic boundaries of uranium-for-energy resources.

Unconventional uranium resources

The nuclear industry classifies the global uranium resources into two categories: conventional and unconventional resources. Phosphates are the main constituent of unconventional uranium resources, other types of uranium-bearing resources (e.g. black shales) are insignificant on global scale.

Phosphates are irreplaceable for agricultural use, so mining of these minerals should be tailored exclusively to agricultural needs. Moreover, the thermodynamic quality of phosphates as a uranium-for-energy source lies beyond the energy cliff: no net energy generation is possible by exploitation of phosphate rock; this holds true also for other unconventional uranium resources, including uranium from seawater.

How much CO2 does nuclear power emit?

Nuclear CO2 emission originates from burning fossil fuels in all processes and factories needed to extract uranium from the ground, prepare nuclear fuel from the recovered uranium, construct the nuclear power plant and to safely manage the radioactive wastes. The fission process in the nuclear reactor is the only process of the nuclear system that has (virtually) no CO2 emission. In addition CO2 is generated by chemical reactions during the production of necessary materials and chemicals, for example cement (concrete) and steel. A generic NPP contains some 150 000 tonnes of steel and 850 000 tonnes of concrete, in addition to several thousands of tonnes of other materials. The sum of all materials consumed by an NPP during its operational lifetime is about 76 grams per kilowatt-hour delivered to the grid, excluding the mass of rock displaced for mining and final sequestration of the radioactive wastes.

By means of the same thermodynamic analysis that revealed the energy cliff, see above, the sum of the CO2 emissions of all processes constituting the nuclear energy system could be estimated at 88-146 gram CO2 per kilowatt-hour. This figure is based on the assumption that all electric inputs of the nuclear process chain are provided by the nuclear power plant itself, to avoid discussions of the local fuel mix of electricity generation.

The large uncertainty range is chiefly caused by uncertainties regarding the processes of the back end of the process chain, these are the processes needed to safely isolate the inevitable radioactive wastes from the biosphere, including the dismantling of the NPP after its service life. The emission figure will rise with time, as will be explained below.

CO2 trap

The energy consumption and consequently the CO2 emission of the recovery of uranium from the earth's crust strongly depend on the ore grade, and several other physical and chemical factors that are not discussed here. In practice the most easily recoverable and richest resources are exploited first, a common practice in mining, because these offer the highest return on investment. As a result of this practice the remaining resources have lower grades and uranium recovery becomes more energy-intensive and more CO2 intensive. Consequently the specific CO2 emission of nuclear power will rise with time; when the average ore grade approaches 200 ppm, the specific CO2 emission of the nuclear energy system will surpass that of fossil-fuelled electricity generation. This phenomenon is called the CO2 trap.

If no new major high-grade uranium resources are found in the future, nuclear power will run aground in the CO2 trap within the lifetime of new nuclear build.

Does nuclear power also emit other greenhouse gases?

No data are found in the open literature on the emission of greenhouse gases other than CO2 by the nuclear system, likely such data never have been published. Assessment of the chemical processes required to produce enriched uranium and to fabricate fuel elements for the reactor indicates that substantial emissions of fluorinated and chlorinated gases are unavoidable; some of these gases may be potent greenhouse gases, with global warming potentials thousands of times greater than CO2.

Unknown are the GHG emissions of the construction of a nuclear power plant, with its large mass of high-quality and often exotic materials. Unknown are the GHG emissions of the operation, maintenance and refurbishment of nuclear power plants. Unknown are the GHG emissions of the backend of the nuclear process chain: the handling and storage of spent fuel and other radioactive waste.

It is inconceivable that nuclear power does not emit other greenhouse gases, this matter is still a well-kept secret. Absence of published data does not mean absence of emissions.

Nuclear power stations and reprocessing plants discharge substantial amounts of a number of fission products, one of them is krypton-85, a radioactive noble gas. Krypton-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. Due to the ionization of air krypton-85 affects the atmospheric electric properties, which gives rise to unforeseeable effects for weather and climate; the Earth's heat balance and precipitation patterns could be disturbed. Would nuclear power exchange alleged mitigation of CO2 emissions for enhanced emissions of climate changer krypton-85?

Are the published nuclear GHG emission figures comparable to renewables?

Scientifically sound comparison of nuclear power with renewables is not possible as long as many physical and chemical processes of the nuclear process chain are inaccessible in the open literature, and their unavoidable emissions cannot be assessed.

When the nuclear industry is speaking about its GHG emissions, only its CO2 emissions are involved.

Erroneously the nuclear industry uses the unit gCO_2eq/kWh (gram CO_2-equivalent per kilowatt-hour), this unit implies that other greenhouse gases also are included in the emission figures, instead the unit gCO_2/kWh (gram CO_2 per kilowatt-hour) should be used. The published emission figures of renewables do include all greenhouse gases. In this way the nuclear industry gives a false and misleading impression of things, comparing apples and oranges.

A second reason why the published emission figures of the nuclear industry are not scientifically comparable to those of renewables is the fact that the nuclear emission figures are based on a very incomplete analysis of the nuclear process chain, for instance the emissions of construction, operation, maintenance, refurbishment and dismantling, jointly responsible for 70% of nuclear CO_2 emissions, are either not taken into account, or use unrealistically low figures. It is these exact components that are the only contributions to the published GHG emissions of renewables. Solar power and wind power do not consume materials for conversion into electricity, as nuclear power does.

What is the energy debt and what are the delayed CO2 emissions of nuclear power?

Only a minor fraction of the back end processes of the nuclear chain are operational, after more than 60 years of civil nuclear power. The fulfillment of the back end processes involve large-scale industrial activities, requiring massive amounts of energy and high-grade materials. The energy investments of the yet-to-be fulfilled activities can be reliably estimated by a physical analysis of the processes needed to safely handle the radioactive materials generated during the operational lifetime of the nuclear power plant. No advanced technology is required for these processes.

The energy investments for construction of the nuclear power plant and those for running the front end processes are offset against the electricity production during the operational lifetime. The future energy investments required to finish the back end are called the energy debt.

The CO_2 emissions coupled to those processes in the future have to be added to the emissions generated during the construction and operation of the NPP if the CO_2 intensity of nuclear power were to be compared to that of other energy systems; effectively this is the delayed CO_2 emission of nuclear power. Whether the back end processes would emit also other greenhouse gases is unknown.

Claiming that nuclear power is a low-carbon energy system, even lower than renewables such as wind power and solar photovoltaics, seems strange in view of the fact that the CO_2 debt built up during the past six decades of nuclear power is still to be paid off.

Conclusions

Assuming nuclear power emits no greenhouse gases (which is not true), the nuclear mitigation share would grow from the present level of less than 1% to at most 1.4% of the global greenhouse gas emissions by 2050-2060, if the global nuclear capacity were to grow according to scenarios projected by the nuclear industry.

Materialization of the nuclear capacity scenarios proposed by the nuclear industry are doubtful because of the unrealistically high construction rates of new nuclear power plants that would be required.

Nuclear generating capacity in the future will have to rely completely on reactors in the once-through mode, because closed-cycle systems, including the thorium cycle, are inherently unfeasible. As a consequence future nuclear power depends exclusively on the availability of natural uranium resources.

Net energy contribution to the global energy supply by nuclear power is limited by the availability of uranium-for-energy resources. Exploiting resources at ore grades below 0.02-0.01% uranium the nuclear system becomes an energy sink instead of an energy source: nuclear power falls off the energy cliff.

The average ore grade and other qualities of the yet-to-be exploited global uranium resources decline with time, because the highest quality resources available are always mined first.

The chances of discovering new major uranium-for-energy resources are bleak.

Mining of phosphates should be tailored exclusively to agricultural needs, for phosphorus is irreplaceable in agriculture.

Uranium from seawater is no option. If feasible at commercial scale at all, this resource lies far beyond the energy cliff: no net energy generation is possible.

From a practical viewpoint only the low IAEA scenario seems feasible, resulting in a mitigation share of 0.5-0.3% of the global GHG emissions by 2050, provided nuclear power is GHG free. The mitigation share would become negligible if the nuclear GHG emissions are taken into account.

At present nuclear power emits 88-146 gCO_2/kWh. Likely the nuclear CO_2 emissions will grow from the current level to values approaching fossil fuel generation within the lifetime of new nuclear builds in the scenarios of both the IAEA and WNA.

Emissions of GHGs other than CO_2 by nuclear power are not reported, but are almost certain from a technical point of view.

Krypton-85, discharged by all nuclear power plants and reprocessing plants, generates greenhouse gases in the troposphere, in addition it causes other weather and climate changing effects.

The published figures of nuclear GHG emissions are not comparable to the figures of renewables, because different quantities and estimation methods are applied.

Due to the *après nous le déluge* culture of the nuclear industry the health hazards posed by radioactive materials in the human environment will increase with time, in addition to risks of Chernobyl-like disasters and of nuclear terrorism.

Radioactive flowers for pro-nuclear politicians

The Dutch woman 'TINKEBELL' is, to put it mildly, a provocative Dutch artist who became famous when she turned her own cat – after having it killed by a doctor − into a handbag. With that 'performance' she highlighted people's hypocrisy about the use of animals for consumption and leather production. Her works provoke discussion about our morals and the way society is developing. She confronts a public that revels in being indignant about everything that has nothing to do with them, but at the same time is very apologetic about their own actions.

She was invited by Green Cross to join a study trip to Fukushima, Japan from September 27 to October 3. Here some of her observations:

"Before I went on this study trip with Green Cross, I didn't know much about nuclear energy. Of course, I read the newspapers and yes, I followed the news after the disaster on March 11 in the year 2011 in Fukushima, Japan but nuclear power felt like a subject that was too difficult to understand without reading a lot of information about it. And I simply never took the time before to get well informed about it.

Now, after 5 days filled with lectures, excursions and a visit to the evacuated city Tomioka and also after talking to refugees from this area and people who live just outside the 'danger zone' and after a lot of discussions with experts with whom I was traveling, I'm still no expert. But. I believe I do understand the essence of the risks of nuclear energy. Which is fear. Nuclear energy is a risk. Always. When things go wrong, like in Fukushima. But actually, really always.

Nuclear waste is something that will never decay ... and there is one tiny thing here on earth that can never be trusted. That's us. People.

When you have to store something as risky and dangerous as nuclear waste there's no such thing as the question 'Will it go wrong?' The question is 'When will it go wrong?'

Also, with radioactivity, of any level, there is always a risk. The higher the level, the higher the risk. But no guarantees. So, if you know that you are or live in a situation in which the risks are higher.

The effect will be fear. Fear causes stress and stress can cause all kinds of mental and physical symptoms and diseases. That's why I illegally picked some flowers in Tomioka, a completely evacuated city approximately 10 km from the heart of the nuclear disaster in Fukushima. I brought these flowers back to the Netherlands and 42 people (a bit random, but mainly politicians, journalists, people who work with nuclear energy and people who believe that nuclear energy is a really good idea) received one of these flowers by mail. The radiation level of these flowers is approximately 20% higher than the radiation level of a 'normal' flower. Which means a higher risk of 20%."

www.tinkebell.com

Nuclear Resister

The latest issue of *Nuclear Resister* is out now, with information about anti-nuclear and anti-war related arrests and peace prisoner support. Stories featured in the latest issue include:

- Five activists, including two military veterans, were arrested at Beale Air Force Base in California on October 20. They were protesting the use of drones by the U.S. around the world that are killing hundreds of civilians, including children. More than 100 people have been arrested at Beale since 2013.
- On October 16, a group of anti-militarist activists impeded the departure of a military convoy from the port of Sagunto, Spain due to be deployed in war maneuvers by army units of more than 30 countries as part of the NATO exercise “Trident Juncture 2015”.
- Before the start of a U.S. Senate Armed Services Committee hearing about Afghanistan, pediatrician and activist Dr. Margaret Flowers was arrested on October 6 for speaking out against the U.S. bombing of a Doctors Without Borders hospital in Kunduz, Afghanistan.
- A long-time anti-war activist was sent to jail for refusing to pay his council tax on the grounds that the UK government is engaged in terrorism. On October 7, Chris Coverdale was imprisoned for 42 days.

To read more and to subscribe to the Nuclear Resister e-bulletin or the print edition, visit: www.nukeresister.org

Meanwhile, in mid-October five Greenpeace activists entered the security zone of what will soon be the world’s biggest nuclear power plant − the Kori nuclear power plant in South Korea. Arriving via an inflatable boat, they climbed out and scampered up a rocky slope unfurling a bright yellow banner in front of the fence of the nuclear plant. For 40 minutes they stood ground as guards looked on, sirens blazed, and warnings from the coast guard were broadcast over the loudspeaker. When the next two planned reactors start operation by 2022, it will become the only nuclear power plant in the world with 10 reactors. Around 3.4 million people live within 30 km of the plant.

www.greenpeace.org/international/en/news/Blogs/nuclear-reaction/when-the-risks-are-so-high-what-would-you-do/blog/54497/

WISE/NIRS Nuclear Monitor

The World Information Service on Energy (WISE) was founded in 1978 and is based in Amsterdam, the Netherlands.

The Nuclear Information & Resource Service (NIRS) was set up in the same year and is based in Washington D.C., US.

WISE and NIRS joined forces in the year 2000, creating a worldwide network of information and resource centers for citizens and environmental organizations concerned about nuclear power, radioactive waste, proliferation, uranium, and sustainable energy issues.

The WISE / NIRS Nuclear Monitor publishes information in English 20 times a year. The magazine can be obtained both on paper and as an email (pdf format) version. Old issues are (after 2 months) available through the WISE homepage: www.wiseinternational.org

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Contact us via:

WISE International
PO Box 59636, 1040 LC Amsterdam, The Netherlands

Web: www.wiseinternational.org

Email: info@wiseinternational.org

Phone: +31 20 6126368

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