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Demystification of Nuclear Energy

Mark Diesendorf

[Each of the following 8 Myths to be placed in its own little box and embedded in various places in the text of the article.]

Myth 1: There is a renaissance in nuclear energy.

Myth 2: Nuclear energy could fill in the [alleged] gap in clean energy supply until renewable energy is ready.

Myth 3: Nuclear weapons cannot be made from the type of plutonium made in a nuclear power station, or from the thorium fuel cycle, or from the integral fast reactor.

Myth 4: Only 30-64 people died as the result of the Chernobyl disaster.

Myth 5: Nuclear power emits no greenhouse gas emissions.

Myth 6: The quantity of nuclear wastes is tiny compared with that of coal wastes.

Myth 7: Nuclear energy is only 20-50% dearer than coal energy.

Myth 8: The only choice for base-load electricity is between coal and nuclear.

Nuclear myths

For the past decade journalists and the general public have been bombarded with claims that nuclear energy is undergoing a renaissance. This alleged renaissance is in turn driven by the claim that nuclear energy is free of greenhouse gas emissions and therefore must become an important part of the solution to the climate change crisis.

Furthermore, we are told that, unlike nuclear energy, renewable energy cannot supply base-load (24-hour) supply. Therefore, since coal with carbon capture and storage is unlikely to be commercially available before 2030, nuclear energy is the only commercially available solution for carbon-free base-load electricity until renewable energy is ready to take over.

Those who are worried about the hazards are reassured by nuclear proponents that there are new generations of nuclear power stations that will be much safer and much cheaper than the old; that even old nuclear power has been responsible for very few deaths; that nuclear weapons cannot be made from the peaceful nuclear fuel cycle; and that nuclear wastes are tiny in quantity and can be managed easily.

This article aims to demystify nuclear energy, while explaining why all the above claims are untrue. Because space is limited, the article cites several non-technical supporting references that address key issues. For more detail on the whole of nuclear energy, see Diesendorf (2007, chapter 12) and the website www.energyscience.org.au.

Global status of nuclear energy

As of 1 April 2011 there were 437 nuclear power stations operating in 30 countries, eight fewer than in 2002, supplying in total about 13% of global electricity. The percentage contribution has been declining steadily through the 2000s as new construction has been balanced by retirements and electricity demand has been growing. The only countries where there is significant growth in nuclear energy are

China, with 27 new generating units¹ under construction, Russia (11), India (6) and South Korea (5). Many existing reactors around the world are coming up for retirement, so it is debatable whether there will be any future global growth in nuclear power (Schneider 2011).

Almost all operating nuclear power stations are classified as Generation II, the types that proliferated in numbers in the 1970s. Several so-called Generation III reactors are under construction in China and two in Europe, but none of these has operated yet. These are actually slightly improved versions of Generation II with almost all the same hazards discussed below. But first:

How it works

Nuclear energy provides a very complicated and expensive way of boiling water. Certain heavy atomic nuclei, such as a type of uranium called uranium-235 and a deadly human-made element called plutonium-239, can be fissioned (split) by bombarding them with subatomic particles called neutrons. When they are split, the energy that was holding them together is released as heat, which is used to boil water. The steam produced turns a turbine, which turns a generator, which generates electricity.

Neutrons are also released, which can split more uranium-235, which releases even more neutrons, and so a self-sustaining chain reaction can be achieved (Figure 1). If this is carefully controlled, you have a nuclear reactor. In a nuclear bomb, pieces of nuclear fuel are suddenly forced together into a critical mass, where neutron production and hence energy release ‘run away’ in a rapid amplification process.

Only a tiny percentage of natural uranium (0.7%) is in the form of the fissile (splittable) uranium-235. So, after uranium ore is mined and milled, using lots of fossil fuel, the uranium is enriched by a physical process to increase the percentage of uranium-235 to 3-5%, a level where fission can occur in a reactor. Further enrichment can produce a nuclear bomb (Figure 2).

The other nuclear weapons explosive that can be obtained from the conventional nuclear fuel life-cycle sketched in Figure 2 is plutonium-239. It is produced in the reactor and with remote handling can be separated from the highly radioactive spent fuel in a chemical process called reprocessing. Some nuclear proponents claim falsely that this ‘reactor-grade’ plutonium cannot be used as a nuclear explosive and that only a military reactor can be tuned for that purpose. The truth is that the US military have successfully tested nuclear bombs based on reactor-grade plutonium. (Roberts, undated)

Accidents at nuclear power stations

It is almost impossible for a nuclear reactor to have a *nuclear* explosion. The reactor has control rods that can be lowered between the fuel elements to absorb neutrons and stop the nuclear reaction. Instead the reactors at Chernobyl and Fukushima experienced hydrogen explosions, which released into the environment (and are still releasing at Fukushima) large quantities of radioactive elements.

A major problem arises because reactors have to be continuously cooled. Even after the fission reaction has been shut down, the core of the reactor continues to generate heat, which comes from the intense radioactivity of the fuel. The energy of

¹ Most power stations have several generating units.

the torrents of invisible alpha, beta and gamma radiation emitted ends up as heat. If the cooling system fails, as it did at the Fukushima reactor and the nuclear reprocessing plant at Kyshtym in the former Soviet Union, the fuel can become so hot that it melts through the containment vessel. The liquid parts can escape into the ground and waterways. If a powerful hydrogen explosion occurs when steam interacts with hot metals in the reactor, the volatile component of the radioactive elements can shoot into the atmosphere. From Chernobyl, vast quantities of highly radioactive elements were spewed over Europe.

Fortunately such major reactor accidents are rare, but the consequences can be huge. Risk can be defined as the probability of the event multiplied by the consequences. It was quite possible that a huge cloud of fallout could have been emitted from Fukushima and 10-12 hours later been deposited on Tokyo. It would have been impossible to evacuate the city and many thousands of cancers could have been induced. Should such rare events be left to chance or should we avoid such unforgiving technologies as nuclear power? (Green 2011a)

The risk of nuclear accidents is also a function of economics. Nuclear reactors and temporary nuclear waste dumps could be made safer by an increase in cost. For example, nuclear reactors could be sited inland and underground. But the nuclear industry has chosen to avoid such improvements and rather to expose the public to higher risks.

Radiation hazards

The principal radiation hazards to the public of the nuclear fuel life-cycle arise from nuclear war (see below), from nuclear accidents or terrorism, and from poor management of nuclear wastes. Normal releases from normally operating nuclear power stations are very low and comparable to radioactivity from coal-fired power stations and coal ash.

There is much debate about the fatal legacy of the Chernobyl disaster. Claims by nuclear proponents that total death toll was in the range 30-64 are misleading, because they ignore the thousands of cancers that will inevitably appear over the 50 years or more since the accident. Science can identify no threshold below which ionising radiation is safe. On the basis of existing scientific evidence, the health hazards are proportional to exposure. Estimates of the expected cancer death toll from Chernobyl vary greatly, because of gaps in basic data and different methods used. Until recently, estimates varied between 9,000 and 93,000 (see summary by Green 2011b). Very recently a few scientific estimates of over a million deaths have been published — these need further evaluation.

Proliferation of nuclear weapons

Nuclear power station disasters can be caused by natural phenomena, such as earthquakes and tsunamis, operator errors (Chernobyl), equipment failures, or terrorist attacks. Nevertheless, the resulting thousands of deaths could be much fewer than those from a nuclear war resulting from the proliferation of nuclear weapons driven in part by so-called ‘peaceful’ nuclear power. Even a regional nuclear war, such as between India and Pakistan, could bring on a ‘nuclear winter’ resulting in global agricultural collapse and mass starvation (Robock and Toon 2009), this in addition to the regional devastation from the blast, firestorms and irradiation.

The governments of the following countries used nuclear power programs to help produce their first nuclear weapons: India, Pakistan, North Korea and South Africa (subsequently dismantled); while the governments of the UK and probably France used nuclear power programs to expand their armouries of nuclear weapons produced originally in military programs.

The governments of the following countries attempted unsuccessfully to use nuclear power to produce nuclear weapons: Argentina, Australia, Brazil, Iran, South Korea and Taiwan. All except Iran discontinued their programs for various reasons before completion. Australia's attempt under the Gorton government in the 1960s was fortunately aborted by a change of Prime Minister (Broinowski 2003).

One of the advantages of using nuclear power, rather than a purely military program, is that it allows a government to come very close to producing nuclear weapons without actually being identified as a nuclear weapons state. For example, Japan has the scientific and engineering capabilities and large quantities of plutonium, so arms control experts believe that Japan could assemble nuclear bombs within a few days or weeks if it decided that the geopolitical situation demanded it.

Clearly, the more nuclear countries that have nuclear power, the greater the probability of nuclear war.

Nuclear wastes

There is no facility for the long-term management of high-level nuclear wastes anyway in the world. After 20 years of planning, Sweden is building one and Finland is still planning one, but the USA has recently terminated work on its facility, Yucca Mountain, after spending about \$10 billion. Globally, most of the spent fuel from the past half-century of nuclear power is stored in pools next to nuclear reactors, where it is gradually cooling both in terms of temperature and radioactivity. Although many of these pools contain much more radioactivity than the core of a reactor, they are not nearly as well contained as the core, as was demonstrated at Fukushima. Temporary storage in dry casks is safer but more expensive.

Nuclear power promoters often claim that the volume of waste from a nuclear power station is tiny compared with the waste from an equivalent coal-fired power station. This is misleading because they are comparing only the high-level waste from the nuclear fuel cycle with *all* the wastes from the coal life-cycle. They are ignoring the vast quantities of low-level radioactive waste from uranium mining. For instance, there is a growing waste mountain, currently of 100 million tonnes, at Olympic Dam uranium/copper mine and it will be blowing in the wind for tens of thousands of years. Over that period the total number of induced cancer deaths could amount to thousands, even though the annual rate is likely to be very small. The total amounts of waste from coal and nuclear energy are of the same order of magnitude.

Greenhouse gas emissions

Contrary to the myth that nuclear power is free of CO₂ emissions, every step of the nuclear fuel cycle except reactor operation involves the combustion of fossil fuels and corresponding emissions (Figure 2). At present, total CO₂ emissions are much less than from coal or gas, but this is changing. In several decades, to obtain 1 kg of yellowcake from low-grade uranium ore, 10 tonnes of rock will have to be mined and milled using diesel fuel. A nuclear physicist and expert on life-cycle assessment, Manfred Lenzen (2008), calculated that nuclear power based on low-grade uranium

ore could produce CO₂ emissions of about one-quarter of an equivalent gas-fired power station. But the studies reviewed by Lenzen made assumptions favourable to nuclear power, for instance that no cover will be placed over the mountains of low-level waste at uranium mines. Adding a cover would further increase energy use and hence emissions to the extent that they could become about half those of an equivalent gas-fired station. Therefore one can argue that conventional (Generations I-III) nuclear power is not an acceptable long-term solution to climate change because of its increasing CO₂ emissions. What about new types of nuclear reactor that are touted as 'clean and green'?

New types of reactor

These are pretentiously called Generation IV, although all are a long way from commercial reality.

The best known is the *fast breeder reactor*, which has been stuck at the demonstration stage for decades. It uses a reactor fuelled on uranium-235 to produce neutrons, which bombard non-fissile uranium-238 forming a 'blanket' around the core, to 'breed' vast quantities of fissile plutonium-239. This kind of reactor produces much more nuclear fuel than it uses, thus reducing greatly the CO₂ emissions from mining and milling uranium. To extract the plutonium, the spent fuel has to be reprocessed, a difficult and expensive chemical process involving remote handling of highly radioactive materials. The fast breeder has much greater proliferation risks than an ordinary reactor and is a nightmare to build and operate. France built the only commercial-scale fast breeder reactor, called Superphénix, which cost about \$15 billion and was closed in 1998 after many technical problems. It only operated intermittently for the equivalent total of one year.

A proposed variant of the fast breeder is the *integral fast reactor*. It is called 'integral' because it would have an on-site reprocessing plant. The latter would perform a new, experimental kind of reprocessing called pyroprocessing, which would separate the long-lived radioactive elements (known as transuranics) as a group from the medium-lived radioactive elements (known as fission products) as a group. Then, in theory, the group of transuranics is fed back into the reactor as a fuel, 'burning' them up. Thus the only wastes left comprise the medium-lived fission products, which decay to negligible radioactivity after several centuries. Since plutonium is (in theory) not separated from the other transuranics, this is the basis of the false claim by its proponents that the integral fast reactor is proliferation-proof.

The flaw in the argument is that, once the highly radioactive fission products have been separated from the less radioactive transuranics, it would become much easier for the owner of the plant to extract the plutonium-239 from the transuranics and use it to produce nuclear weapons. This is the reason why the US government discontinued research on this system.

Another concept is the *thorium reactor* (see <<http://www.world-nuclear.org/info/inf62.html>>), which is based on a different set of reactions from a uranium reactor. Thorium is more abundant in nature than uranium, so this approach may postpone the growth in CO₂ emissions from mining and milling the fuel. In theory, thorium could have other potential advantages: most (but not all) of the wastes from a thorium reactor would only have to be managed for about 500 years instead of hundreds of thousands of years; and in some thorium systems there could be advantages in reactor safety.

But many people have been misled by the incorrect claim, made in popular articles, that nuclear weapons cannot be made from the thorium system. Thorium is not fissile, so it first has to be bombarded with neutrons to convert it into uranium-233, which is fissile. Like any fissile element, uranium-233 can be used either to generate heat and hence electricity, or as a nuclear explosive.

India has been trying for many years to develop a complicated thorium system involving three stages: uranium reactors to produce plutonium; then fast breeder reactors using plutonium as fuel to breed uranium-233 from thorium; and then another conventional reactor to fission the uranium-233. This system, if it ever gets going, would have none of the theoretical advantages of the thorium reactor apart from the more abundant fuel. It would have proliferation risks, long-lived wastes and risks of reactor accidents.

Yet another new type of proposed reactor is the *pebble bed reactor*, in which the fuel is encapsulated in 'pebbles' the size of tennis balls made of graphite. It has potential advantages in terms of safety and efficiency of energy conversion. Some of its disadvantages are that the graphite can burn if it comes into contact with air and that the quantity of high-level radioactive waste from the pebbles is much larger than from an ordinary reactor, which holds the fuel in rods. The technology was first developed in Germany, then abandoned, and more recently in South Africa, then abandoned in 2010 (Thomas 2011). China has a small prototype and plans to build a medium-sized demonstration plant, but this has been delayed.

Economics

Commercial nuclear power has only been possible because governments (that is, taxpayers and electricity consumers) have carried most of the risk of major accidents. In the USA the Price-Anderson Act and its amendments limit the liability of owners and operators of nuclear power stations. In Japan there is currently fierce debate about who should pay for Tokyo Electric Power Company's growing liabilities for the Fukushima accident, amounting to tens of billions of dollars. The problem is that the company may be too big to be allowed to fail (Hayashi 2011).

In addition to risk coverage by the public, for the past 50 years nuclear energy has received, and continues to receive, huge subsidies for research and development, uranium enrichment, waste management, decommissioning of power stations and loan guarantees. Estimated total for USA is about \$100 billion.

In most countries with nuclear energy, the real costs of nuclear energy are hidden and the only information comes from vendors of nuclear power stations, which have a vested interest in underestimating the costs. However, even with the huge subsidies, no new nuclear power station has been built in the USA for the past 30 years. Detailed desktop studies by utilities and financial institutions show that the cost of a new nuclear power station in the USA has escalated rapidly since the early 2000s, that it's already higher than the cost of wind power and, if its escalation continues, could soon become higher than solar power (Diesendorf 2010).

Nuclear energy is unnecessary

Australia has huge renewable energy resources in terms of sunshine west of the Great Dividing Range, hot rocks under the Great Artesian Basin, wind along the southern and south-western coasts and on the tablelands of NSW, and biomass residues in all states. There is also significant wave potential along the southern coastline. In the

long-term we could be exporting renewable energy in the form of hydrogen to countries less blessed with these resources.

In the time it takes to plan and build a nuclear power station and its associated infrastructure in Australia (about 15 years), it is likely that all of the above sources will be less expensive than nuclear. In addition, efficient energy use can be implemented rapidly with economic savings. Renewable energy technologies (except large hydro and tidal with dams) can be built very quickly, because their components are manufactured in production lines and on-site erection is a minor part of the process and can also be done en masse. On the other hand nuclear power stations are very slow to build because they are huge construction projects that have to be individually adapted to each site.

The principal objection to a renewable energy future, namely that it cannot supply base-load (24-hour) electric power, is refuted in a non-technical article by Diesendorf (2011) and the references therein.

Conclusion

We do not have to choose between coal or nuclear, that is, between BHP Billiton and Rio Tinto on one hand and BHP Billiton and Rio Tinto on the other. The real choice is between dirty and dangerous technologies (coal and nuclear) and genuinely clean technologies (energy efficiency and renewable energy).

Existing types of nuclear power station are not a long-term solution to climate change because they are potentially as dangerous as climate change, by increasing the risk of nuclear war, and because of their increasing CO₂ emissions from uranium mining and milling as high-grade uranium ore depletes. They are not a short-term solution because they are too slow to build. Some types of the proposed future generation reactors avoid the problem of CO₂ emissions while introducing others. Not one is proliferation-proof.

Nuclear energy is a dangerous and expensive diversion from real solutions to climate crises and energy security.

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Figure 1: Nuclear fission

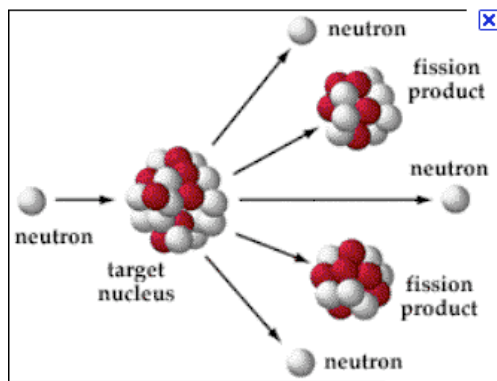


Figure 2: The nuclear fuel life-cycle

