NUCLEAR ACCIDENTS & ATTACKS

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the Medical Association for Prevention of War www.mapw.org.au
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1. INTRODUCTION

"A reactor in one day produces as much radioactivity as a 50-kt nuclear explosion, and fuel in a reactor has typically been there for an average of two years, a typical nuclear reactor has in its core the long-lived radioisotopes from 30 megatons of fission."
–– Nuclear physicist Richard Garwin (2001)

Comparisons of the risks associated with different energy sources need to consider several factors:
1. Power plant accidents.
2. Accidents at other stages of the energy chain (e.g. uranium mining, spent nuclear fuel stores).
3. Impacts of routine operations and emissions.
4. Attacks on power plants and other stages of the energy chain (by nation-states or sub-national groups).
5. Weapons/WMD proliferation risks.

Claims that nuclear power is safe, or that it is one of the safest energy sources, often rest on flawed assessments of the risks and impacts of power plant accidents, and completely ignoring the other four aspects of risk assessment. A typical example is the Switkowski Report (2006, p.77) which includes a table on fatal accidents in the worldwide energy sector from 1969–2000. The figures are given in terms of deaths per gigawatt-year (the amount of electrical energy generated by a 1 GW power plant over the course of one year):

LPG	3.54
Coal	0.876
Hydro	0.561−4.265 (higher figure includes a major dam accident in China in 1975)
Natural gas	0.093
Nuclear	0.006

The Switkowski Report (2006) states: "The record of such accidents shows that the nuclear power industry is significantly safer than other large scale energy-related industries."

However when both accidents and routine emissions across the energy chain are considered, and when the estimated long-term Chernobyl death toll is included, renewable energy sources are shown to be far less hazardous than both coal and nuclear power. The following table includes not only accidents but also impacts from routine operations (e.g. emissions of radioactive substances from coal fired power plants and the nuclear fuel cycle). It notes two major hazards associated with some energy sources − WMD proliferation, and global warming − although it is impossible to meaningfully quantify those risks. (The calculations for the table below are discussed in Appendix 1.)

Fatalities per gigawatt-year	
Coal	9.7 − 31.2 + global warming
Nuclear (without reprocessing)	<7.7 − 15.4 + WMD proliferation
Nuclear (with reprocessing)	<8.2 − 31.4 + WMD proliferation
Oil	4.5 + global warming
LPG	3.5 + global warming
Biomass	1.4
Hydro	0.6−4.3 (higher figure includes a major dam accident in China in 1975)
Gas	0.5 + global warming
Solar (rooftop)	0.05
Wind	0.02

Chernobyl

There is no doubt that average safety standards have improved since the Chernobyl disaster. Improvements can be seen both at the technical level and also the social level (improvements in the management and operation of reactors). Nevertheless, the potential for catastrophic accidents remains. Serious challenges confront the industry, including the following:

- The unevenness of safety standards.
- The ageing of the global nuclear workforce and the consequent loss of skills both for the operation of nuclear facilities and for regulatory bodies.
- Pressures arising from the expansion of nuclear power, such as increased skills shortages.
- Safety challenges will be greater in countries developing nuclear power for the first time, especially countries with limited technical and industrial bases, inadequate regulation, or widespread corruption.
- The 'bathtub effect' − a likely scenario in the coming 20 years is that an increasing majority of the global fleet of power reactors will be very young or very old, the two phases of a reactor's lifespan when they are most accident-prone.
- Inadequate regulation in a number of countries, including advanced nuclear countries such as the US and Japan.
- The ongoing potential for commercial imperatives to reduce safety margins in a number of ways.
- The push to limit or abolish public participation in decision-making and licensing processes, a push which is driven by commercial imperatives and could adversely effect nuclear safety.
- The ongoing potential for attacks on nuclear plants whether by nation-states or sub-national groups (terrorists).

2. ACCIDENT RISK ASSESSMENT

The Massachusetts Institute of Technology (MIT) Interdisciplinary Study on the future of nuclear power notes that expert opinion using Probabilistic Risk Assessment (PRA) estimates the risk of an accident damaging the nuclear core of a power reactor to be about 1/10,000 per reactor per year in the US. (PRA estimates the frequency of possible failures that could lead to damage to the reactor core, such as pipe breaks or loss of coolant flow.) (Ansolabehere et al., 2003).

The MIT Study team envisaged a growth scenario leading to a near-tripling of nuclear output by 2055 to 1000 GWe, and concluded: "With regard to implementation of the global growth scenario during the period 2005-2055, both the historical and the PRA data show an unacceptable accident frequency. The expected number of core damage accidents during the scenario with current technology would be 4."

Nuclear advocates claim significantly reduced risks for the 'next generation' of nuclear power reactors. The Switkowski Report (2006) states that improvements in design for future nuclear power plants are expected to lead to a risk of 1/100,000 per reactor per year for accidents damaging the nuclear reactor core. The IAEA safety target for future plants is 1/100,000.

Needless to say, risk assessments of reactor types that have yet to be built or operated are speculative. Moreover, even for existing reactors, PRA is based on a myriad of assumptions and estimates. Former ANSTO nuclear engineer Tony Wood (2001) notes that PRA failed to anticipate the events which led to the world's worst reactor accident (Chernobyl) and the worst reactor accidents in the UK (Windscale) and the USA (Three Mile Island).

The US Nuclear Regulatory Commission (NRC) noted in a 2002 report: "Senior NRC officials confirmed that the agency is highly reliant on information from licensee risk assessments. Agency officials also noted that there are no PRA standards, no requirements for licensees' PRAs to be updated or accurate, and that the quality of the assessments varies considerably among licensees." (NRC, 2002b)

3. 'NEXT GENERATION' REACTORS

While the nuclear industry is promoting a new generation of 'passively safe' reactors, closer inspection reveals that improved safety features fall a long way short of the sweeping claims being made.

So-called Generation III reactors feature standardised designs offering advantages over most of the world's currently operating (Generation II) reactors. These include 'passive' safety features which depend only on physical phenomena such as convection, gravity or resistance to high temperatures, not on functioning of engineered components.

The only operating Generation III reactors are four advanced boiling water reactors in Japan. Other Generation III reactors are under construction including the reactor in Finland which is well over budget and behind schedule. Licensing of some other Generation III reactor designs − in particular the AP1000 and EPR designs − has been protracted and has yet to be completed.

Hirsch et al. (2005) summarise: "All in all, 'Generation III' appears as a heterogeneous collection of different reactor concepts. Some are barely evolved from the current Generation II, with modifications aiming primarily at better economics, yet bearing the label of being safer than current reactors in the hope of improving public acceptance. Others are mostly theoretical concepts so far, with a mixture of innovative and conventional features, which are being used to underpin the promise of a safe and bright nuclear future – while also not forgetting about simplification and cost-cutting."

A director of a US research laboratory has noted that "fabrication, construction, operation, and maintenance of new reactors will face a steep learning curve: advanced technologies will have a heightened risk of accidents and mistakes." (Quoted in Sovacool, 2010.) Another nuclear industry insider has quipped: "We know that the paper-moderated, ink-cooled reactor is the safest of all. All kinds of unexpected problems may occur after a project has been launched." (Quoted in Hirsch et al., 2005.)

More radical 'Generation 4' reactor concepts are a long way from deployment. The Generation 4 International Forum website states that "commercial deployment of Gen-IV reactors is not foreseen before 2030 at the earliest, and all current activities involving Gen-IV designs are at the level of R&D." The World Nuclear Association (2009) is also downbeat, noting that "progress is seen as slow, and several potential designs have been undergoing evaluation on paper for many years."

Regarding Generation IV concepts, Hirsch et al. (2005) state: "A closer look at the technical concepts shows that many safety problems are still completely unresolved. Safety improvements in one respect sometimes create new safety problems. And even the Generation IV strategists themselves do not expect significant improvements regarding proliferation resistance. But even real technical improvements that might be feasible in principle are only implemented if their costs are not too high. There is an enormous discrepancy between the catch-words used to describe Generation IV for the media, politicians and the public, and the actual basic driving force behind the initiative, which is economic competitiveness."

(For further discussion on safety aspects of Generation III and IV concepts, see Schaper et al., 1999; Froggatt, 2006; Hirsch et al., 2005; World Nuclear Association, 2010.)

4. SOCIAL AND ECONOMIC CHALLENGES

The MIT Interdisciplinary Study states: "We do not believe there is a nuclear plant design that is totally risk free. In part, this is due to technical possibilities; in part due to workforce issues. Safe operation requires effective regulation, a management committed to safety, and a skilled work force." (Ansolabehere et al., 2003, p.9.)

Serious, unresolved problems remain on all three fronts – regulation, management, and workforce skills. The safety culture varies considerably within and between nations operating nuclear power plants. As the MIT Study notes: "It is still an open question whether the average performers in the industry have yet incorporated an effective safety culture into their conduct of business."

A report by the International Atomic Energy and the OECD's Nuclear Energy Agency covering events during the 2002-2005 period stated (IAEA/NEA, 2006):

"About 200 events have been reported by the participating countries during that period... Almost all of the events reported during that period have already occurred earlier in one form or another. It shows that despite the existing exchange mechanisms in place at both national and international levels, corrective measures, which are generally well-known, may not reach all end-users, or are not always rigorously or timely applied. ...

"Recently, some top regulators expressed their concerns with respect to the international effort devoted to operational experience. They notably noticed that:
• A worldwide observation is that operating experience feedback (OEF) needs to be much improved in the international arena.
• There is a tendency to consider that foreign OEF is not relevant.
• The global effort in the area of event reporting does not appear to be functioning as it should.

Schneider et al. (2007) state: "After accidents in Three Mile Island and Chernobyl a large number of measures were introduced in order to improve the safety during reactor operation: improvement of operational procedures, implementation of comprehensive quality systems, development of emergency operating procedures, intensive training of personal including simulator training, etc. All these measures were expected to result in significant improvements of operational safety during the following years. However, there is evidence ... that despite these measures there was little or no further improvement during recent years and concerns have been expressed in many international forums regarding complacency in the industry."

At the October 2003 meeting of the World Association of Nuclear Operators, chairman Hajimu Maedae of a creeping lethargy that begins with "loss of motivation to learn from others ... overconfidence ... (and) negligence in cultivating a safety culture due to severe pressure to reduce costs following the deregulation of the power market." (MacLachlan, 2003)

The ageing of the global nuclear workforce, and the loss of expertise as waves of skilled workers reach retirement (a 'silver tsunami'), will be a major challenge in coming years and decades (Hirsch et al., 2005).

The workforce challenge will be all the greater if nuclear power expands rapidly. Conversely, skills shortages pose an obstacle to rapid nuclear growth.

A likely scenario is modest growth of nuclear power to 2030, at which time a large majority of reactors will be either very young or very old (www.choosenuclearfree.net/renaissance). This has serious safety implications as reactors are most accident-prone in their early years (break-in phase) and in their old age (wear out phase). (Lochbaum, 2004; Hirsch et al., 2005)

The safety challenges will be greater in countries developing nuclear power for the first time, especially countries with limited technical and industrial bases, inadequate regulation, or widespread corruption. The International Panel on Fissile Materials (2010) notes: "A major effort ... will be necessary to ensure that countries building nuclear power plants for the first time, or rapidly expanding their reactor fleet, put effective safety measures in place, including instilling a strong culture of safety and granting independent regulators the power, resources and expertise to do their jobs."

Regulation is at best uneven between countries. Inadequate regulation is evident in advanced nuclear countries such as the US and Japan (as illustrated in the case studies below) and regulation has been problematic in Australia. Problems include 'captured bureaucracies', the revolving door between regulatory bodies and regulated organisations, and shortages of skilled personnel to adequately carry out regulatory functions.

Shreyans Jain, then newly-elected President of the World Association of Nuclear Operators (WANO), stated in his acceptance speech in 2007 (WANO, 2007): "The key issues that demand world attention today, in my opinion, are those related to the ageing work force, ageing reactors, global increase in the fleet of nuclear power plants and probably, the hesitation of the younger generation to embrace this technology as a profession. It is also a fact that with the increased turnover of work force, the invaluable tacit knowledge, built up through years of experience, is steadily being lost. It is therefore absolutely essential for all of us to put on our thinking caps and evolve methods to tackle these serious issues."

There are many points of intersection between safety and economics. South Africa illustrates the potential for economics to undermine safety. South Africa planned to develop 'pebble bed' gas-cooled reactors, claimed to be far less accident prone than conventional reactors. Those plans have been abandoned for economic reasons. South Africa also planned to purchase a number of 'Generation 3' reactors, but those plans were also abandoned for economic reasons. Now, plans are slowly being developed to purchase cheaper 'Generation 2' reactors. (MacLachlan, 2010)

Another important point of intersection between safety and economics concerns legislated caps on payouts in the event of an accident. One well known example is the Price-Anderson Act in the US. Lochbaum (2004) states: "Price-Anderson may prevent safety upgrades from being incorporated into new reactor designs. Without Price-Anderson, the added cost of developing and incorporating safety features is offset by reduced annual insurance premiums. With Price-Anderson providing equal liability protection regardless of risk, the cost of additional safety features becomes a financial impediment."

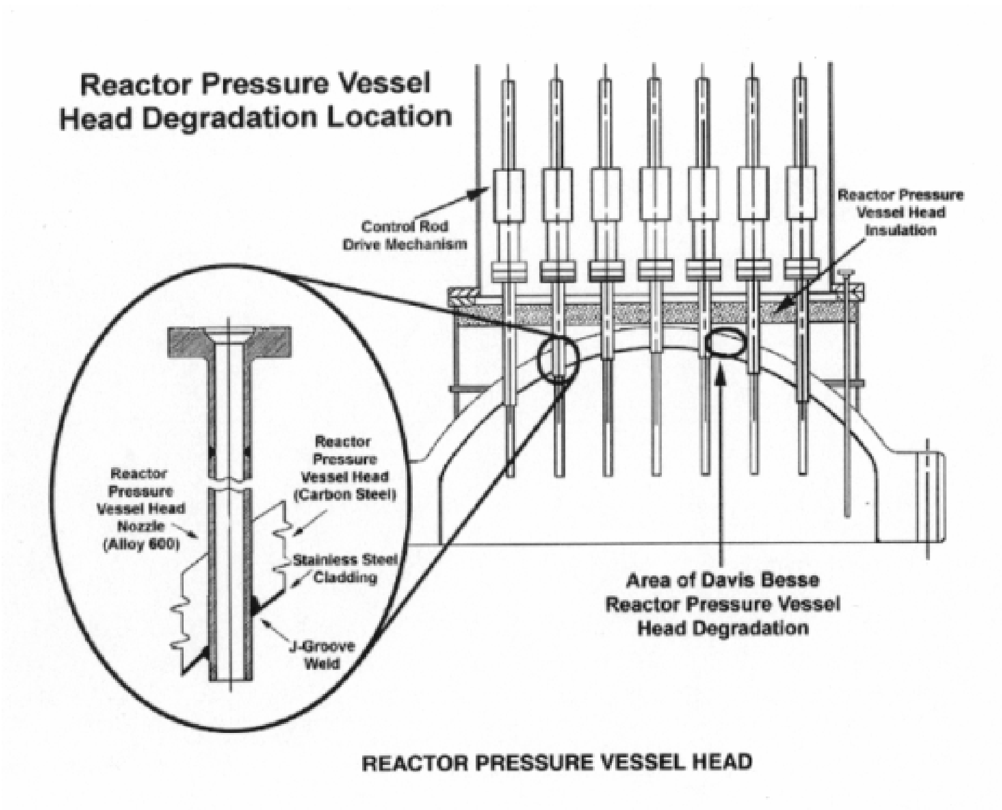
Another point of intersection between safety and economics is the push to limit or abolish public participation in decision-making and licensing processes, a push which is driven by commercial imperatives. Lochbaum (2004) states that the US Nuclear Regulatory Commission's "Atomic Safety and Licensing Board has documented many examples of reactor safety improvements resulting from public participation ...Unfortunately, the NRC, bowing to industry pressure, recently revised its licensing process to virtually eliminate public participation, except in the role of casual observer."

5. CASE STUDY − UNITED STATES

At the Davis-Besse nuclear power plant in Ohio, it was discovered in 2002 that boric acid had almost eaten through a 15 cm thick reactor pressure vessel head. The corrosion exposed the stainless steel liner, which was for years the only barrier preventing a loss-of-coolant accident. A government study estimated that the hole would have widened to the point where the liner ruptured in another 2−11 months of operation. Emergency backup systems were also found to be impaired. (Schneider et al., 2007; Lochbaum, 2004)

Many warning signs had been overlooked since the leak began in 1996. Commercial imperatives were given priority over reactor safety. Regulatory oversight by the US Nuclear Regulatory Commission (NRC) was insufficient.

An NRC report said: "NRC appears to have informally established an unreasonably high burden of requiring absolute proof of a safety problem, versus lack of reasonable assurance of maintaining public health and safety, before it will act to shut down a power plant." (NRC, 2002)



Above and below: Davis-Besse reactor, Ohio, USA: large hole in the reactor vessel head.

Physicist David Lochbaum (2004) wrote: "The NRC often states that risk insights cut both ways − they can trim regulations having little or no safety merit and they can also impose requirements in previously undervalued areas. But in practice, the NRC's risk-informed sword is razorsharp on the side that slashes regulations and dull on the side that enforces regulations. [Dozens of examples] show that the NRC abides by or abandons its absolute proof standard as necessary to allow nuclear plants to continue operating. The NRC must immediately stop admitting or rejecting circumstantial evidence based on the answer it is seeking. The data must determine the outcome, not vice versa."

Lochbaum also noted in his 2004 report on nuclear power in the US:

- the number of significant safety-related events had decreased in recent years but the rate of "near-misses" (elevated risks of reactor meltdown) appeared to have increased: "In other words, while the number of events is decreasing, their severity is increasing, with the near-misses getting nearer and nearer to disaster."
- 27 nuclear power reactors were shut down between 1984−2004 for more than a year for extensive repairs to safety equipment: "Years of overlooking problems and applying "band-aid" fixes at these plants resulted in a backlog of safety problems that took a long time to resolve."

6. CASE STUDY − JAPAN

On 29 August 2002 the Japanese Nuclear Industrial Safety Agency (NISA) revealed a massive data falsification scandal carried out by the Tokyo Electric Power Company (TEPCO). At that point 29 cases of "malpractice" had been identified, including the falsification of the operator's inspection records at its nuclear power plants over many years. All of TEPCO's 17 reactors had to be shut down for inspection and repair. It was also reported later that these practices had gone on for as long as 25 years and the total number of events is put at nearly 200. In September 2002 additional cases of malpractice were revealed involving two other nuclear operators, Chubu Electric Power Company and Tohoku Electric Power Company. (Schneider et al., 2007)

NISA (2002) said: "As nuclear safety regulatory authorities, NISA regards the recent cases as a very serious problem, not only with safety arrangements at licensees who have performed inappropriate acts but also with Japan's nuclear safety regulatory administration itself. The cover-up cases have made us painfully aware that we must frankly reflect on what we have done, take the plunge and mend our ways."

There have been numerous other documented incidents of data falsification involving reactors in Japan in the years since 2002. (Schneider et al., 2007; WISE/NIRS, 2007; Japan Times, 2010; World Nuclear News, 2010; World Nuclear News 2009; Tsukimori, 2007; Lies, 2007)

Accidents at Japanese nuclear facilities over the past decade include (WISE/NIRS, 2002; WISE/NIRS, 2007; Schneider et al., 2007):

- Sodium leak at the Monju fast breeder in December 1995.
- Tokai reprocessing waste explosion in March 1997.
- At the Kozloduy nuclear power plant in May 1998, the emergency core cooling system and spray system was without a water supply for 24 hours, contrary to license requirements. This event was categorized as INES Level 2 due to a serious reduction in defence-in-depth and the adverse safety culture of the plant executives and personnel.
- In 1999, 50 tonnes of primary coolant leaked from a reactor at Tsuruga, leading to a sharp increase of radiation levels inside the reactor building.
- Following a criticality accident at a uranium conversion plant at Tokaimura in 1999, two people died and hundreds were irradiated.
- In 2001, a water pipe at Hamaoka-1 exploded, releasing radioactive steam into the containment building

- In 2002, 16 workers were irradiated after a water pipe leak at Hamaoka-2.
- On 9 August 2004, five workers were killed and six injured after a pipe rupture and steam leak at the Mihama-3 nuclear power plant. It was later revealed that the thickness of the wall of the failed pipe had not been checked since the plant went into operation in 1976.
- Fukushima, 2011 − an earthquake and tsunami result in limited access to electricity and compromised water cooling systems, leading to a cascade of events including exposure of fuel and spent fuel as water levels fell, fires, explosions, and emergency responses compromised by radiation levels, fresh water shortages, etc.

In addition, earthquakes have effected several nuclear plants in Japan, the most serious being the major 2007 earthquake which led to the shutdown of all operating reactors at the Kashiwazaki-Kariwa Nuclear Power Plant in Niigata. Radiation releases included small leaks of radioactive liquids and the release of small quantities of radionuclides resulting from 400 drums of low-level nuclear waste which were knocked over by aftershocks, 40 losing their lids.

Following criticism's over TEPCO's response to the earthquake, Nuclear Engineering International reported: "Japan's nuclear industry has been suffering in the glare of negative publicity brought about by revelations that operators had covered up accidents and problems for decades. When it became public knowledge, it was hoped that the public relations disaster that companies were engineering for themselves might lead the wider industry to realise the potential benefits of being more open and honest when problems do crop up. That hope seems to have withered again in Niigata." (Ryall, 2007)

The Japanese Citizens Nuclear Information Centre commented (White and Yamaguchi, 2009):

"Prior to establishment of the Kashiwazaki-Kariwa Nuclear Power Plant there were oil fields in the region. Studies related to these oil fields showed that the ground was unstable, so informed locals knew very well that it was an unsuitable place to construct a nuclear power plant. Why then was such a site chosen for a nuclear power plant? The answer is simple: Kakuei Tanaka of Lockheed bribery scandal fame. Kakuei Tanaka, either as Prime Minister, or as the man pulling the strings behind the scenes, was Japan's political strong man. He was from Nishiyama Town, just north of Kashiwazaki City. He had a sizable shareholding in real estate company Muromachi Sangyo and in practice controlled the company. The site of the Kashiwazaki-Kariwa Nuclear Power Plant (KK) was bought up by Muromachi Sangyo and later sold to Tokyo Electric Power Company (TEPCO). Money changed hands several times in the process and it is said that Tanaka's profit from the land sale was 400 million yen ($11 million at the time). Under these circumstances, it is not hard to imagine that concerns about seismic safety were never going to stand in the way of construction of the plant. ...

"Proponents of nuclear power in other earthquake-prone countries point to Japan as a role model. However, the history of the seismic assessment and design of Japan's nuclear power plants suggests that it is more by luck than good management that Japan has managed to escape a nuclear earthquake catastrophe."

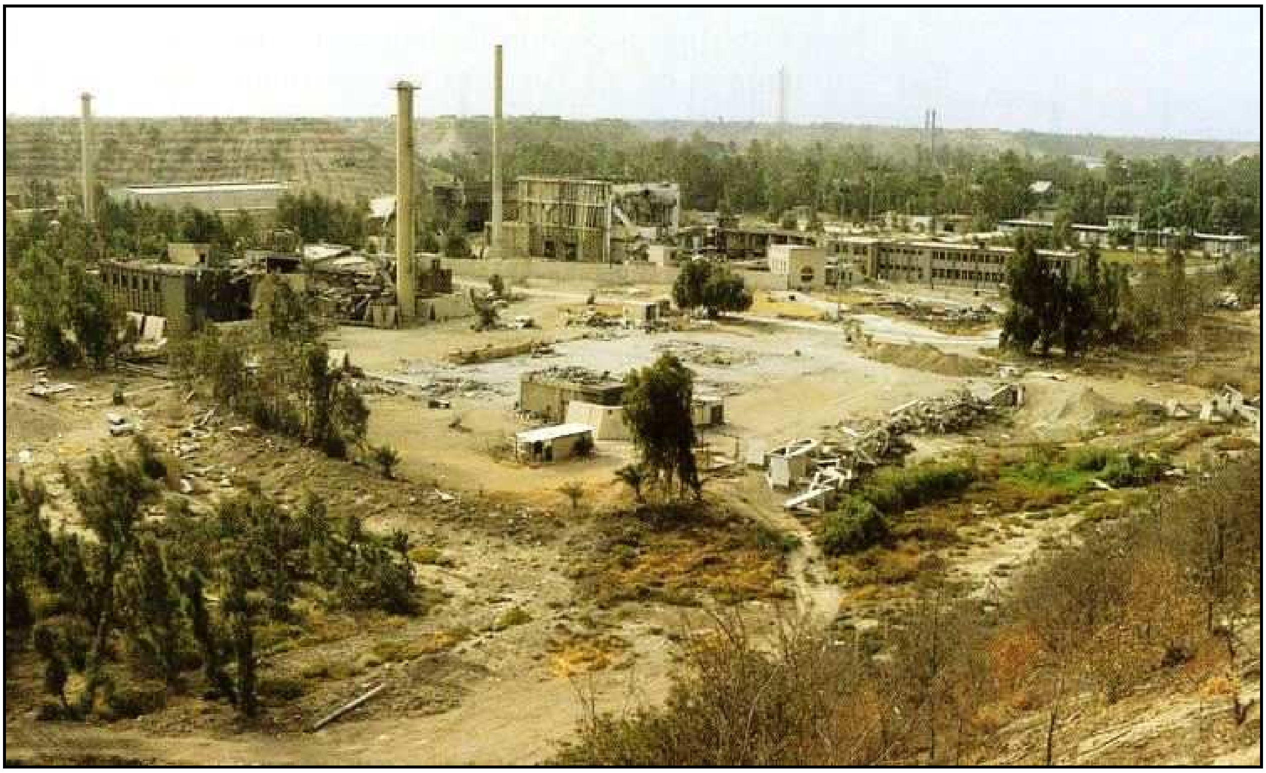
All seven reactors at the Kashiwazaki-Kariwa plant − the largest nuclear plant in the world − were involved in the 2002 data falsification scandal.

7. MILITARY ATTACKS ON NUCLEAR PLANTS

Historical examples of military strikes on nuclear plants include the following:

- Israel's destruction of a research reactor in Iraq in 1981.
- the US destruction of two smaller research reactors in Iraq in 1991.
- attempted military strikes by Iraq and Iran on each other's nuclear facilities during the 1980-88 war.
- Iraq's attempted missile strikes on Israel's nuclear facilities in 1991.
- Israel's bombing of a suspected nuclear plant in Syria in 2007.

Most of the above examples have been motivated by attempts to prevent WMD proliferation. Nuclear plants might also be targeted with the aim of widely dispersing radioactive material or, in the case of power reactors, disrupting electricity supply.



Osiraq research reactor site destroyed by an Israeli bomb strike in 1981.

If and when nuclear-powered nations go to war, they will have to choose between shutting down their power reactors, or taking the risk of attacks potentially leading to widespread, large-scale dispersal of radioactive materials.

Garwin (2001) poses these questions: "What happens with a failed state with a nuclear power system? Can the reactors be maintained safely? Will the world (under the IAEA and U.N. Security Council) move to guard nuclear installations against theft of weapon-usable material or sabotage, in the midst of chaos? Not likely."

There are examples of IAEA safeguards being suspended in the event of war or domestic political turmoil, including Iraq in 1991, some African states, and Yugoslavia.

8. TERRORISM AND SABOTAGE

Terrorism involving nuclear weapons or radioactive materials could take a wide variety of forms:
Steal, buy or otherwise acquire a ready-made nuclear weapon.

Steal, buy or otherwise acquire fissile material which could be fabricated (with difficulty) into a crude nuclear bomb.
Make and detonate a radiological weapon, or 'dirty bomb', to spread radioactive material.
Attack a nuclear reactor or other nuclear facility (e.g. reprocessing plant, spent nuclear fuel store)
Disrupt critical inputs for the safe running of a nuclear reactor eg water supply for cooling, electrical power supply systems.
Attack or steal nuclear fuel or waste containers, most likely in transit.
Disrupt the operation of a nuclear plant with a sophisticated computer virus or worm (e.g. the Stuxnet worm which has disrupted operations at Iran's uranium enrichment plant and also infected some computers at Iran's nuclear power plant).

While it is very difficult or impossible to meaningfully assess the likelihood or frequency of terrorist attacks, the potential for catastrophic outcomes is not in dispute. A 12.5 kiloton bomb detonated in New York City is estimated to cause (Helfand et al., 2002):
52,000 immediate deaths;
238,000 people exposed to direct radiation, of which 10,000 would die and 44,000 would suffer acute radiation sickness;
1.5 million people would be exposed to radioactive fallout in the following few days – this could kill an additional 200,000 people.

Reprocessing plants and stores for spent nuclear fuel and high-level nuclear waste typically contain enormous quantities of radioactive materials in readily dispersible forms, and are more vulnerable to attacks than reactors as they are generally less well protected. (Hirsch, 2005) Barnaby (2003) states: "It is hard to think of a nuclear terrorist attack which could, at least in theory, be more catastrophic than a successful attack on either the tanks at Sellafield that contain the liquid fission products separated from spent reactor fuel elements by the two reprocessing plants or on the stores holding the plutonium separated by the reprocessing plants."

The IAEA's Illicit Trafficking Database contains more than 1000 confirmed reports on incidents involving smuggling, theft, loss and illegal disposal, illegal possession and transfer, and attempted illegal sales of nuclear material. Around 800 additional incidents are as yet unconfirmed. Globally, the number of reported incidents of trafficking has been increasing through some combination of increased trafficking and better detection. (<www-ns.iaea.org/security/itdb.htm>)

The IAEA relies on voluntary funding (as opposed to predictable core funding) for 90% of its nuclear security program and 30% of its nuclear safety program (IAEA, 2008). In 2006, then IAEA Director-General Dr Mohamed El Baradei said: "Everybody says nuclear terrorism is the No. 1 national and international security issue. But until they translate this grandstanding statement into dollars and cents, we will not be able to deal effectively with the danger we are facing." (Dickey, 2006.)

Many of the difficulties faced by would-be nuclear terrorists can be overcome if they have the support of 'insiders' − plant employees or contractors. Hirsch et al. (2005) state: "The insider problem is of particular complexity. Generally, at present, qualified personnel for nuclear plants are scarce. Sub-contractors are extensively used. This considerably increases the "chances" for terror organisations to recruit insiders."

Schneider et al. (2007) discuss the situation in the US: "While there has not been a documented case of sabotage at a nuclear power plant resulting in a radiological release, numerous incidents over the last twenty years have revealed serious security vulnerabilities that could have been exploited in the event of an attack. These vulnerabilities should be considered comparable to vital safety systems that are nonfunctional. ... Typically, after events like these, the U.S. Nuclear Regulatory Commission (NRC) will take steps to address the vulnerabilities that were exposed. However, even after the revamping of the NRC's security programs in the aftermath of the 11 September 2001 attacks, incidents of concern continue to occur, often brought to the attention of the public through whistleblowers, indicating that the systemic problems in security are not being addressed."

The 'insider' problem (among others) is discussed in a US Secretary of State (2010) cable released by Wikileaks:

"Russia is aware that Pakistani authorities, with help from the U.S., have created a well-structured system of security for protecting nuclear facilities, which includes physical protection. However, there are 120,000-130,000 people directly involved in Pakistan's nuclear and missile programs, working in these facilities and protecting them. However, regardless of the clearance process for these people, there is no way to guarantee that all are 100% loyal and reliable.

"In addition to the Islamist interest in these facilities, Russia also is aware that Pakistan has had to hire people to protect nuclear facilities that have especially strict religious beliefs, and recently the general educational and cultural levels in Pakistan has been falling.

"Due to these facts, extremist organizations have more opportunities to recruit people working in the nuclear and missile programs. Over the last few years extremists have attacked vehicles that carry staff to and from these facilities. Some were killed and a number were abducted and there has been no trace seen of them. Also, even if places are well protected, transportation of materials is a vulnerable point. In Pakistan, it is hard to guarantee the security of these materials during transportation."

On transport risks, Hirsch et al. (2005) state:

"During transport, radioactive substances are a potential target for terrorists. Of the numerous materials being shipped, the following are the most important:
1. Spent fuel elements from nuclear power plants and highly active wastes from reprocessing (high specific inventory of radioactive substances)
2. Plutonium from reprocessing (high radiotoxicity, particularly if released as aerosol)
3. Uranium hexafluoride – uranium has to be concerted into this chemical form in order to undergo enrichment (high chemical toxicity of released substances, resulting in immediate health effects in case of release).

"Since the amounts transported with one shipment are about several tonnes at most, the releases to be expected will be smaller by orders of magnitudes than those that result from attack of a storage facility – even if the transport containers are severely damaged. On the other hand, the place where the release occurs cannot be foreseen, as attacks can occur, in principle, everywhere along the transport routes. Those routes often go through urban areas; for example at ports or during rail transport. Thus, releases can take place in densely populated regions, leading to severe damage to many people, even if the area affected is comparatively small."

Terrorist incidents involving nuclear plants include the following (Hirsch, 2005; Ruff, 2006):
- On 12 November 1972, three hijackers took control of a DC-9 of Southern Airlines and threatened to crash it on the Oak Ridge military nuclear research reactor. The hijackers flew on to Cuba after they obtained two million dollars.
- March 1973: guards at a nearly completed nuclear power reactor at Lima, Argentina were overpowered in an attack by 15 armed men.
- December 1977: Basque separatists set off bombs damaging the reactor vessel and a steam generator and killing two workers at the Lemoniz nuclear power plant under construction in Spain.
- January 1982: 4 anti-tank rockets were fired at the nearly-completed Superphenix fast breeder reactor at Creys-Malville, France, damaging the containment vessel.

- December 1982: ANC fighters set off four bombs inside the Koeberg plant under construction in South Africa, despite tight security.
- May 1986: three of the four off-site power lines leading to the Palo Verde nuclear power plant in Arizona were sabotaged by short-circuiting.
- February 1993: At Three Mile Island nuclear power plant (Pennsylvania), a man crashed his station wagon through the security gate and rammed the vehicle under a partly opened door in the turbine building. Security guards found him hiding in that building four hours later.
- In 1993, the terrorists behind the car bombing against the World Trade Centre, belonging to the terrorist networks that claimed to be part of the Islamic jihad, threatened to target nuclear sites in a letter received by the New York Times and authenticated by the authorities.
- November 1994: Bomb threat at Ignalina nuclear power plant, Lithuania. However, no explosion occurred and no bomb was found in the power plant.

Incidents at ANSTO's Lucas Heights nuclear site in southern Sydney include the following (Ruff, 2006):

- 1983: nine sticks of gelignite, 25 kg of ammonium nitrate (usable in explosives), three detonators and an igniter were found in an electrical substation inside the boundary fence. A detonator was set off but did not detonate the main explosives. Two people were charged.
- 1984: a threat was made to fly an aircraft packed with explosives into the HIFAR reactor; one person was found guilty of public mischief.
- 1985: after vandalism of a pipe, radioactive liquid drained into Woronora river, and this incident was not reported for 10 days. In 1986 an act of vandalism resulted in damage to the sampling pit on the effluent pipeline.
- 2000: in the lead-up to the Sydney Olympics, New Zealand detectives foiled a plot to attack the reactor by Afghan sympathisers of Osama bin Laden.
- 9 October 2001: NSW and Federal police conducted a full search following a bomb threat directed at ANSTO.
- December 2001: Greenpeace activists easily breach security at the front gate and the back fence of Lucas Heights, some activists scale the reactor while another breaches the 'secure air space' in a paraglider.
- October 2003: French terror suspect Willy Brigitte deported from Australia, held on suspicion of terrorism in France; alleged to have been planning to attack the reactor and to have passed on bomb-making skills to two Australians.
- November 2005: multiple coordinated arrests of terrorist suspects in Sydney and Melbourne. Court documents reveal the Lucas Heights reactor was a potential target. Three of the eight alleged members of the Sydney terror cell had previously been caught near the reactor facility by police in December 2004, each alleged to have given different versions of what they had been doing.
- November 2005: a reporter and photographer were able to park a one-tonne van for more than half an hour outside the Lucas Heights back gate, protected by a simple padlock able to be cut with bolt-cutters, 800 m from the reactor. The Australian reported: "The back door to one of the nation's prime terrorist targets is protected by a cheap padlock and a stern warning against trespassing or blocking the driveway." (Porter, 2005)
- A man facing terrorism charges in 2007 had purchased five rocket launchers allegedly stolen from the army. According to a witness statement, the accused purchaser said "I am going to blow up the nuclear place", an apparent reference to Lucas Heights. (Neighbour, 2007; Ferguson, 2007)

Up to 13,000 people could require iodine, and/or be evacuated, to counter the effects of radiation if terrorists destroyed the core of the nuclear reactor at Lucas Heights, according to a NSW Health Department study. (Macey, 2005) Nuclear engineer Tony Wood, former head of ANSTO's Division of Reactors and Engineering, told a Senate inquiry that the OPAL reactor at Lucas Heights "when operating at full power will contain sufficient fission products to cause great damage off site if a large fraction were to escape."

The existing reactor, and the proposed new reactor, are not the only risks at Lucas Heights. The isotope processing plant, in which irradiated targets, including enriched uranium targets, are processed, is vulnerable. Another target at Lucas Heights is the spent fuel from the reactor. On April 2, 1996, maritime workers refused to load a shipment of spent fuel from ANSTO because they had not been forewarned of the shipment. The spent fuel was driven aimlessly around Sydney while the dispute was resolved, because of a law preventing the convoy being stationary for more than two hours (presumably for security reasons). (SMH 5/9/98.) During a previous spent fuel shipment was, a spent fuel convoy from Lucas Heights was followed onto a ship by a truck driven by Greenpeace activists.

9. INFORMATION ON NUCLEAR ACCIDENTS

Sovacool (2010) has documented 99 accidents at nuclear power plants. He states: "No less than 99 nuclear accidents (defined as incidents that either resulted in the loss of human life or more than US$50,000 of property damage, the amount the US federal government uses to define major energy accidents that must be reported), totalling US$20.5 billion in damages, have occurred world-wide from 1952 to 2009. These numbers translate to more than one incident and US$330 million in damages every year for the past three decades. ... Fifty-seven accidents have occurred since the Chernobyl disaster in 1986, and almost two-thirds (56 out of 99) of all nuclear accidents have occurred in the USA, refuting the notion that severe accidents are relegated to the past or to countries without US modern technology or industry oversight." (Sovacool 2010; see also Sovacool, 2008)

The Los Alamos National Laboratory lists 60 criticality accidents − accidental nuclear chain reactions in fissile material such as enriched uranium or plutonium. (Monahan et al., 2000) Of the 60 accidents, 38 occurred at research or experimental facilities such as research reactors, while 22 occurred in commercial nuclear facilities.

Abnormal events in nuclear plants are triggered by a variety of reasons (Schneider et al., 2007):

- design errors
- construction, manufacturing and materials faults and/or deficiencies that have remained hidden in the plant
- unforeseen and unprepared for external events that unexpectedly challenge the plants and their safety systems
- 'internal events' such as fires
- the human dimension, including slip ups, omissions and misunderstandings, or more complex and deeply rooted institutional errors and the possibility of malicious acts against nuclear plants.

Schneider et al. (2007, ch.9) discuss 16 power reactor accidents in common light-water reactors since 1986. The accidents are categorised according to cause of failure:

- Advanced Material Degradation (before break)
- Significant Primary Coolant Leaks
- Reactivity Risks
- Fuel Degradation (outside reactor core)
- Fires and Explosions
- Station Blackout
- Generic Issues – Reactor Sump Plugging
- Natural Events
- Security Events and Malicious Act

Numerous lists of nuclear accidents can be found at Wikipedia, e.g.:

- List of civilian nuclear accidents

http://en.wikipedia.org/wiki/List_of_civilian_nuclear_accidents

- Lists of nuclear disasters and radioactive incidents.

http://en.wikipedia.org/wiki/Lists_of_nuclear_disasters_and_radioactive_incidents

The Australian Radiation Protection and Nuclear Safety Agency publishes lists of radiation incidents in Australia:
http://arpansa.gov.au/RadiationProtection/arir/arir_reports.cfm

The IAEA's International Nuclear Event Scale (INES) provides some information on nuclear accidents − but not a great deal. The scale defines events as "deviations" (Level 0), "anomalies" (Level 1), "incidents" (Level 2) "serious incidents" or "near accidents" (Level 3) and "accidents" (Levels 4 to 7). INES is problematic for various reasons (Schneider et al., 2007):

- a small number of the most recent events is available online with short descriptions at the IAEA's website but the selection and publication criteria remain unclear.
- it is reliant on information provided by the operators of the affected plants or of the national regulatory authorities − there is no system of independent evaluation, and national governments have radically different approaches to the classification and reporting of nuclear incidents and accidents.
- the INES system is poorly placed to appropriately register the importance of 'near misses', events where there was little or no radiological release but a catastrophe was narrowly averted.
- the INES database is confidential (as is the accident database of the OECD's Nuclear Energy Agency).

Accident reporting templates vary dramatically between countries. There are no clearly established benchmarks to describe, categorise and assess events from one country to another. Schneider et al. (2007) state: "In recent years the French nuclear power plant operator, EDF, has reported annually between 600 and 800 'significant incidents' ... to the nuclear safety authorities. Of over 10,000 events that were reported between 1986 and 2006, most were considered below the INES scale or Level 0 while 1,615 incidents were rated INES Level 1 and 59 Level 2. One event has been given a Level 3 rating. In comparison, since the implementation of INES in 1991 Germany reported over 2,200 events as Level 0 or below, while 72 events were rated Level 1 or higher. On its part, the US Nuclear Regulatory Commission, over the same time period, has only reported 22 events to the IAEA and rated them on the INES scale, of which 6 below scale, 7 Level 0, 3 Level 1, 5 Level 2 and 1 Level 3."

Sometimes non-government organisations try to plug information gaps; for example the Union of Concerned Scientists has an online 'Nuclear Power Information Tracker' for US reactors:
www.ucsusa.org/nuclear_power/reactor-map/embedded-flash-map.html

10. AUSTRALIA'S TRACK RECORD WITH NUCLEAR PROJECTS

The Switkowski Report (2006) states: "There is every reason to be confident that Australia's health and safety systems will continue to provide a sound framework for the management of the uranium mining industry and would enable any other parts of the nuclear fuel cycle envisaged for Australia to be equally well regulated, ensuring the highest levels of health and safety."

However there is a wealth of contrary evidence concerning the record of organisations involved in the nuclear sector in Australia.

Uranium mining

A report by a federal Senate References and Legislation Committee (2003) found "a pattern of under-performance and noncompliance" in the uranium mining industry. It identified many gaps in knowledge and found an absence of reliable data on which to measure the extent of contamination from the uranium mining industry, and it concluded that changes were necessary "in order to protect the environment and its inhabitants from serious or irreversible damage". The committee concluded "that short-term considerations have been given greater weight than the potential for permanent damage to the environment".

Nuclear radiologist Dr Peter Karamoskos (2010), the public representative on ARPANSA's Radiation Health Committee, states: "On several occasions in recent years uranium mining companies have brought guest speakers to Australia to argue that low-level radiation exposure is not only harmless but actually good for you. To promote such marginal views without any counter-balance is self-serving and irresponsible and it may be time for governments to step in to provide that balance. Recent research has heightened rather than lessened concern about the adverse health impacts of low-level radiation. Moreover the latest science − concerning the health impacts of exposure to radon gas − is important in the context of the ongoing debate over uranium mining in Australia."

ARPANSA

In the late 1990s, the federal government undermined the independence of the newly-created regulatory agency, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), by allowing the chief executive of the Australian Nuclear Science and Technology Organisation to sit on the panel which interviewed applicants for the position of CEO of ARPANSA.

The Australian National Audit Office (ANAO, 2005) wrote a report critical of many aspects of ARPANSA's operations. The Audit Office's overall conclusions were as follows:

"The ANAO concluded that improvements are required in the management of ARPANSA's regulatory function. While initial under-resourcing impacted adversely on regulatory performance, ARPANSA's systems and procedures are still not sufficiently mature to adequately support the cost-effective delivery of regulatory responsibilities.

"In particular, deficiencies in planning, risk management and performance management limit ARPANSA's ability to align its regulatory operations with risks, and to assess its regulatory effectiveness.

"As well, procedures for licensing and monitoring of compliance have not been sufficient, particularly as a licence continues in force until it is cancelled or surrendered. Current arrangements do not adequately support the setting of fees in a user-pays environment, nor ARPANSA's responsibilities for transparently managing the potential for conflict of interest."

ARPANSA illustrates a problem common with nuclear regulators − potential conflicts and biases arising from a 'revolving door' between regulatory bodies and the organisations they regulate.

Federal government

The Coalition government comprehensively mismanaged the Maralinga nuclear 'clean up' project in the late 1990s. Nuclear engineer Alan Parkinson (2002) commented: "The disposal of radioactive waste in Australia is ill-considered and irresponsible. Whether it is short-lived waste from Commonwealth facilities, long-lived plutonium waste from an atomic bomb test site on Aboriginal land, or reactor waste from Lucas Heights. The government applies double standards to suit its own agenda; there is no consistency, and little evidence of logic."

An ARPANSA officer complained about a "host of indiscretions, short-cuts and cover-ups" by the federal government during the Maralinga clean-up. (ABC Background Briefing, 2000.)

The Coalition government's handling of its plan for a national radioactive waste dump in SA from 1998-2004 was the subject of sustained, informed criticism. For example nuclear physicist Prof. Peter Johnston (2004) commented on the federal government's Department of Education, Science and Training (DEST): "... DEST is responsible for the Former Nuclear Test site at Maralinga, as well as the Repository project. DEST was an ineffective manager of the Maralinga Cleanup in a number of key ways. The pattern of contracting required services for the Repository project is similar to the Maralinga cleanup. ... The applicant has inadequate technical competence to manage its contractors." (For more information see Friends of the Earth, 2005)

DEST was notorious for misleading the South Australian public about its nuclear dump plans from 1998-2004. For example, its claims that SA was the "best and safest" site for a dump, that most of the waste was of medical origin, and that the dump would accept only low-level waste, were all demonstrably false yet they were repeated ad nauseum.

Many of the problems evident with the abandoned plan for a dump in SA are now evident with the plan for a dump at Muckaty in the Northern Territory. That plan was conceived by the Coalition government and has been pursued by the Labor government since the 2007 election. Among other problems:

- the government has put the National Radioactive Waste Management Bill before Parliament, draft legislation which overrides all state/territory laws and overrides key federal environmental protection and Aboriginal heritage protection laws.
- the government is pursuing enactment of the National Radioactive Waste Management Bill despite unresolved legal action in the Federal Court initiated by Muckaty Traditional Owners.
- the government has adopted a selective approach to consultation with Traditional Owners − those who support a dump are consulted, those opposed are ignored.
- the government has not established the need for a national repository
- Muckaty was not even short-listed when scientific and environmental criteria underpinned a preliminary site selection process in the 1990s.
- the approach is in conflict with federal ALP policy and clear promises made before the 2007 federal election.

ANSTO

ANSTO has a poor track record in many respects. Tony Wood, former head of the Divisions of Reactors and Engineering at ANSTO's reactor plant in Sydney, has criticised ANSTO for its "misleading public statements" and for "sugar-coating" its information. Mr. Wood said in 2001: "I believe that it is very important that the public be told the truth even if the truth is unpalatable. I have cringed at some of ANSTO's public statements. Surely there is someone at ANSTO with a practical reactor background and the courage to flag when ANSTO is yet again, about to mislead the public." (Wood 2001; 2001b)

Mr. Wood said: "Another document called the Sutherland Shire Local Disaster Plan is needed to cater for the public. This plan is a most remarkable document. In this case the vulnerable community represents the people in the Sutherland Shire who would be exposed in the event of a reactor accident and it lists a number of hazards to which they might be exposed, such as bushfires, earthquakes, oil spills and aircraft crashes, but there is no mention of radioactivity, among the hazards. In the whole document there is no mention of the words "iodine" or "nuclear" or " reactor" and only one mention of "ANSTO". No one would guess from reading this plan that there was a nuclear reactor in the area."

A culture of secrecy undermines community confidence in ANSTO's waste management (and more generally). This culture has been the subject of frequent criticism, e.g.:

- the Senate Select Committee Inquiry into the Contract for a New Reactor at Lucas Heights, Final Report, May 2001, said: "The Committee is highly critical of ANSTO's approach to providing documents. Its attitude seems to stem from a culture of secrecy so embedded that it has lost sight of its responsibility to be accountable to the Parliament."
- Ex-ANSTO scientist and then President of the Australian Nuclear Association, Dr. Clarence Hardy, complained about the "culture of secrecy" at ANSTO when giving evidence to a parliamentary Public Works Committee inquiry in 1999.
- In 2000, the Sydney Morning Herald and Greenpeace were told that to acquire two and 22 pages of information respectively under Freedom of Information requests, they would be charged $7099 and $6809.
- The government/ANSTO PR strategy in relation to the OPAL reactor was discussed by a senior government official on ABC radio: "The government decided to starve the opponents of oxygen, so that they could dictate the manner of the debate that would follow the announcement. Because they couldn't win it on rational grounds ... they decided, right, we'll play the game and in the lead up to the announcement catch them totally unawares, catch them completely off-guard and starve them of oxygen until then." (ABC Background Briefing, 1998)

ANSTO (then called the Australian Atomic Energy Commission) was heavily involved in Australia's one and only serious push for a power reactor in Australia, pursued from the late 1960s until the early 1970s. It was later revealed that the plan for a reactor at Jervis Bay on the east coast was driven by a hidden agenda to produce plutonium for nuclear weapons.

ASNO

Lastly, the Australian Safeguards and Non-proliferation Office (ASNO) is a dishonest and unprofessional government agency and arguably has an even worse track record than the organisations mentioned above. (EnergyScience Coalition, 2007)

11. APPENDIX 1 − COMPARATIVE ASSESSMENT OF ENERGY SOURCES − CALCULATIONS

Fatalities per gigawatt-year	
Coal	9.7 − 31.2 + global warming
Nuclear (without reprocessing)	<7.7 − 15.4 + WMD proliferation
Nuclear (with reprocessing)	<8.2 − 31.4 + WMD proliferation
Oil	4.5 + global warming
LPG	3.5 + global warming
Biomass	1.4
Hydro	0.6−4.3 (higher figure includes a major dam accident in China in 1975)
Gas	0.5 + global warming
Solar (rooftop)	0.05
Wind	0.02

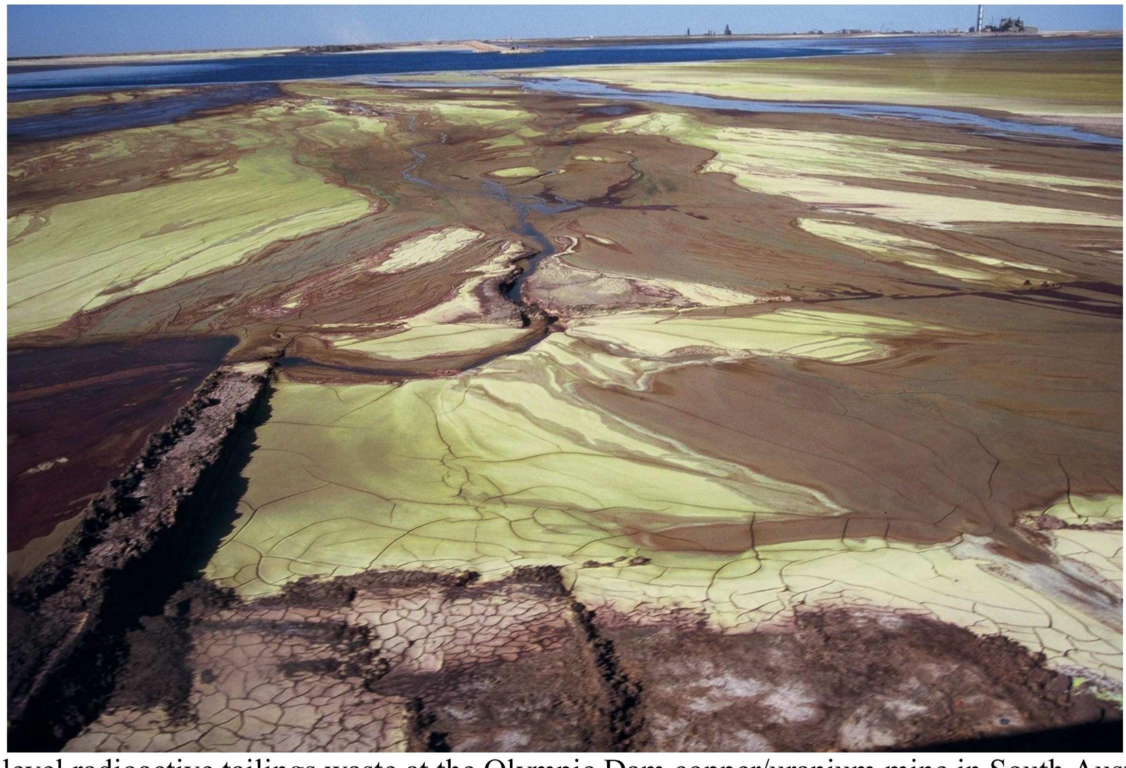
The above table is based on the following:

For nuclear power:

- A typical estimate of the total Chernobyl death toll is 24,000 (based on the International Atomic Energy Agency's (1996) estimate of collective dose of 600,000 person-Sieverts over 50 years from

Chernobyl fallout, and a risk estimate of 0.04 fatal cancers per person-Sievert). This equates to approximately 1.7 fatalities per GW-year averaged over the worldwide experience with nuclear power (24,000 deaths divided by 14,270 GW-years of operation of nuclear power reactors).

- For routine emissions and exposures across the nuclear fuel cycle, US nuclear physicist Richard Garwin (2001) estimates six fatalities per GW-yr for nuclear power without reprocessing (and 6.5−14 deaths per GW-yr with reprocessing). A large majority of the estimated radiation exposure arises from uranium mine and mill tailings, considered for a period of 10,000 years. A figure similar to Garwin's (without reprocessing) can be calculated from the United Nations Scientific Committee on the Effects of Atomic Radiation'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 of two million person-Sieverts (UNSCEAR, 1994). Applying a standard risk estimate of 0.04 fatal cancers per person-Sievert gives a total of 80,000 fatal cancers. Dividing the estimated 80,000 deaths by 14,270 GW-years of operation of nuclear power reactors (as at December 2010) gives a figure of 5.6 deaths per Gw-yr.
- For nuclear power the estimated death toll is based almost entirely on low-level radiation, both from Chernobyl fallout and from routine emissions across the nuclear fuel chain. The US Committee on the Biological Effects of Ionizing Radiation comprehensively reviewed evidence regarding the health effects of low level radiation. The Committee concluded that the linear no-threshold model is the best fit with the available evidence, but that the evidence is "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." (BEIR VII Report, 2006, p.6). Thus for nuclear power without reprocessing, the figure of 7.7 deaths / GW-yr (1.7 from Chernobyl and 6 from routine emissions) could be reduced or it could be doubled to 15.4 fatalities per Gw-yr. With reprocessing (0.5−8 deaths per Gw-yr), the total is 8.2−15.7, and adjusted for uncertainty over the effects of low-level radiation, <8.2−31.4.
- A thorough assessment of the hazards associated with nuclear power would need to take account of the risks of attacks on nuclear plants, nuclear terrorism, and also the contribution of the nuclear fuel cycle to WMD proliferation risks. Unfortunately it is near-impossible to quantify those risks. WMD proliferation risks are identified in the table above but no attempt is made to quantify the risk.



Low-level radioactive tailings waste at the Olympic Dam copper/uranium mine in South Australia.
Photo by Jessie Boylan.

For coal:

- Estimates of fatalities from air pollutants such as carbon monoxide, sulphur dioxide and heavy metals vary considerably. A study by the Ontario Ministry of Energy indicates 668 deaths / 27 TWh of coal-based electricity generation which equates to 24.7 deaths/TWh or 2.8 deaths/GW-yr (Polya, 2008). The Lifeboat Foundation (2010) estimates 1.7 deaths/GW-yr for the US, 31.7 for China, and 18.3 as a world average. The table above uses the Canadian figure as the lower estimate and the Lifeboat Foundation's world average as the upper estimate − 2.8 to 18.3 deaths / GW-yr.
- Garwin (2001) estimates a death rate of six deaths / GW-yr for coal just from radiation exposure, mostly from the use of coal ash as a construction material. In the table above, a range of 6−12 is used reflecting uncertainty about the health effects of low-level radiation.
- Add the above figures to the Switkowski Report's (2006) figure of 0.876 deaths per GW-yr for accidents gives a total of 9.676 to 31.176 deaths / GW-yr (rounded to 9.7 − 31.2)
- Climate change is probably the greatest risk associated with coal − it is identified in the table above but no attempt has been made to quantify the risk.

Oil, gas and LPG:

- Figures for oil and gas are from the Lifeboat Foundation (2008; 2010)
- The LPG figure is for accidents only, taken from the Switkowski Report (2006)

Solar, wind and biomass:

- In the table above, figures have been added for wind power (Gipe, 2009), rooftop solar power (Lifeboat Foundation, 2010) and biomass (Lifeboat Foundation, 2010).

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