Submission to the Federal Parliament's Standing Committee on Environment and Energy

'Inquiry into the prerequisites for nuclear energy in Australia'

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Australian Conservation Foundation
Greenpeace Australia Pacific
The Wilderness Society
Nature Conservation Council (NSW)
Conservation SA
Conservation Council of WA
Queensland Conservation Council
Environment Victoria

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1. EXECUTIVE SUMMARY

Friends of the Earth Australia, the Australian Conservation Foundation, Greenpeace Australia Pacific, The Wilderness Society, the NSW Nature Conservation Council, Conservation SA, the Conservation Council of WA, the Queensland Conservation Council and Environment Victoria welcome the opportunity to provide a submission to this inquiry. The lead authors of the submission, Dr. Jim Green (Friends of the Earth) and Dave Sweeney (Australian Conservation Foundation), would welcome the opportunity to appear before a public hearing of the Committee to elaborate on the contents of the submission.

There appears to be consensus that, in the words of Dr. Ziggy Switkowski at the Committee's 29 August 2019 hearing, "the window is now closed for gigawatt-scale nuclear" in Australia. Dr. Switkowski further noted that "nuclear power has got more expensive, rather than less expensive", that "there's no coherent business case to finance an Australian nuclear industry", and that no-one knows how a network of SMRs might work in Australia because no such network exists "anywhere in the world at the moment".

The 2006 Switkowski report estimated the cost of electricity from new reactors at A$40–65 per megawatt-hour (MWh). That is one-quarter of current nuclear cost estimates such as those provided in the November 2018 Lazard's report (A$166–280/MWh or $US112–189).

In 2009, Dr. Switkowski said that the construction cost of a 1,000-megawatt (MW) power reactor in Australia would be A$4–6 billion. Again, that is one-quarter of the current cost estimates for all reactors under construction in western Europe and the US (A$17.8–24 billion).

Even without factoring in those four-fold cost increases – blowouts amounting to A$10 billion or more per reactor – Prime Minister Scott Morrison cited the findings of the 2006 Switkowski report when providing a sceptical response to a question about the economic viability of nuclear power for Australia.

As a result of catastrophic cost overruns with recent reactor projects, numerous nuclear lobbyists acknowledge that the industry is in crisis and engage each other in debates about what if anything can be salvaged from the "ashes of today's dying industry". One consequence of the industry crisis is that it sharply limits finance options and explains the growing clamour for ever-larger, multi-billion-dollar public subsidies (such as the estimated A$55–91 billion lifetime subsidies for the Hinkley Point reactor project in the UK).

The industry crisis also limits the number of potential vendors of reactor technology – companies such as Westinghouse and Toshiba are no longer willing to take on the huge financial risks. For Australia, the Australian Nuclear Association suggests South Korea as a potential supplier of reactor technology. However, as discussed in Appendix 1 to this submission, the South Korean nuclear industry suffers from sustained allegations of endemic corruption.

South Korea's four-reactor project in the UAE is said to be a welcome contrast to the vastly over-budget and long-delayed projects in western Europe and the US, but the UAE project is at least three years behind schedule (partly because of the corruption scandal involving South Korean manufacturers) and costs are reported to have increased from A$29.7 billion to A$47.3 billion (US$20 billion to US$32 billion). Remarkably, the South Korea / UAE reactor contract was accompanied by a secret military side-agreement (see Appendix 1).

'Advanced' or 'Generation IV' nuclear power concepts

With respect to 'advanced' or 'Generation IV' nuclear power concepts, the findings of the 2015/16 South Australian Nuclear Fuel Cycle Royal Commission still hold. Numerous lobbyists and enthusiasts made the case for the introduction of 'advanced' nuclear reactors to South Australia but the Royal Commission concluded:
"[A]dvanced fast reactors or reactors with other innovative designs are unlikely to be feasible or viable in South Australia in the foreseeable future. No licensed and commercially proven design is currently operating. Development to that point would require substantial capital investment. Moreover, the electricity generated has not been demonstrated to be cost-competitive with current light water reactor designs."

Claims that Generation IV concepts and small modular reactors (SMRs) are leading to 'cleaner, safer and more efficient energy production' have no evidentiary basis. Given that no Generation IV reactors have commenced operation in recent years while numerous Generation IV and SMR projects have been abandoned, the only way such assertions could be justified would be with reference to concepts that exist only as designs on paper.

The words of Admiral Hyman Rickover, a pioneer of the US nuclear program, are as relevant now as when they were penned in 1953:
"An academic reactor or reactor plant almost always has the following basic characteristics: (1) It is simple. (2) It is small. (3) It is cheap (4) It is light. (5) It can be built very quickly. (6) It is very flexible in purpose ('omnibus reactor'). (7) Very little development is required. It will use mostly off-the-shelf components. (8) The reactor is in the study phase. It is not being built now.
"On the other hand, a practical reactor plant can be distinguished by the following characteristics: (1) It is being built now. (2) It is behind schedule. (3) It is requiring an immense amount of development on apparently trivial items. Corrosion, in particular, is a problem. (4) It is very expensive. (5) It takes a long time to build because of the engineering development problems. (6) It is large. (7) It is heavy. (8) It is complicated. …
"For a large part those involved with the academic reactors have more inclination and time to present their ideas in reports and orally to those who will listen. Since they are innocently unaware of the real but hidden difficulties of their plans, they speak with great facility and confidence. Those involved with practical reactors, humbled by their experience, speak less and worry more."

Examples of Generation IV and SMR projects that have been abandoned, sharply curtailed or postponed in recent years include the following:

- The French government has abandoned the planned 100–200 MW ASTRID demonstration fast reactor due to waning interest in fast reactor technology (and Generation IV concepts more generally) as well as funding constraints (which, in turn, are partly due to five-fold cost overruns with a 100 MW materials testing reactor and the extraordinary cost overruns with large Generation III EPR reactors under construction in France and Finland).
- The Russian government has postponed plans for a 1200 MW fast neutron reactor (currently there are only five such reactors worldwide, all of them smaller reactors classified as experimental or demonstration reactors by the World Nuclear Association).
- Babcock & Wilcox abandoned its mPower SMR project in the US despite receiving government funding of US$111 million.
- Transatomic Power gave up on its molten salt reactor R&D in 2018.

- Westinghouse sharply reduced its investment in SMRs after failing to secure US government funding.
- China is building a 210 MW demonstration high-temperature gas-cooled reactor but it is it is behind schedule and over-budget, and plans for additional high-temperature reactors at the same site have been "dropped" according to the World Nuclear Association.
- MidAmerican Energy gave up on its plans for SMRs in Iowa after failing to secure legislation that would require rate-payers to partially construction costs.
- Rolls-Royce sharply reduced its SMR investment in the UK to "a handful of salaries" and is threatening to abandon its R&D altogether unless massive subsidies are provided by the British government.
- TerraPower abandoned its plan for a prototype fast neutron reactor in China due to restrictions placed on nuclear trade with China by the Trump administration.
- The UK government abandoned consideration of 'integral fast reactors' for plutonium disposition in March 2019 – and the US government did the same in 2015.

The 'advanced' nuclear sector is regressing, not advancing. It is a high-risk sector, hence the deep reluctance of the private sector and national governments to invest.

The last Generation IV reactor to commence operation was a fast neutron reactor in Russia in 2014 but, as mentioned, Russia has postponed plans for a larger fast neutron reactor. The next Generation IV reactor to commence operation may be the long-delayed, over-budget 'Prototype Fast Breeder Reactor' (PFBR) in India. Construction of the reactor began in 2004 and it is almost a decade behind schedule. The PFBR has a blanket with thorium and uranium to breed fissile uranium-233 and plutonium respectively; in other words, it will be ideal for weapons production.

India plans to use fast reactors to produce weapon-grade plutonium for use as driver fuel in thorium reactors – plans which are highly problematic with respect to weapons proliferation and security as John Carlson, the former Director-General of the Australian Safeguards and Non-proliferation Office, has repeatedly noted.

There is nothing 'cleaner, safer and more efficient' about India's 'advanced' reactor program. On the contrary, it is dangerous and it fans regional tensions and proliferation risks – all the more so since India refuses to allow IAEA safeguards inspections of its 'advanced' nuclear power program.

Legislation banning nuclear power should be retained

Our organisations believe that Howard-era federal legal prohibitions against the construction of nuclear power reactors have served Australia well and should be retained. We welcome the current bipartisan political consensus that these prudent prohibitions should be retained.

Legislation banning nuclear power has saved Australia from the huge costs associated with failed and failing reactor projects in Europe and North America, such as the Westinghouse AP1000 project in South Carolina that was abandoned after the expenditure of at least US$9 billion (A$13.4 billion). The South Carolina fiasco could so easily have been replicated in any of Australia's states or territories if not for the Howard Government's wise decision to enact legal prohibitions.

Legislation banning nuclear power should also be retained because nuclear power could not possibly pass the two economic tests set by Prime Minister Scott Morrison. Firstly, nuclear power could not possibly be introduced or maintained without huge taxpayer subsidies. Secondly, nuclear power would undoubtedly result in higher electricity prices.

Legislation banning nuclear power should also be retained because there is no social license to introduce nuclear power to Australia (as Dr. Switkowski acknowledged at the 29 August 2019 hearing of this inquiry). Every opinion poll over the past decade has found <50% support for the introduction of nuclear power; opinion polls find that Australians are overwhelmingly opposed to a nuclear power reactor being built in their local vicinity (10–28% support, 55–73% opposition); and opinion polls find that support for renewable energy sources far exceeds support for nuclear power (for example a 2015 IPSOS poll found 72–87% support for solar and wind power but just 26% support for nuclear power).

Legislation banning nuclear power should also be retained because the pursuit of a nuclear power industry would almost certainly worsen patterns of disempowerment and dispossession that Australia's First Nations have experienced – and continue to experience – as a result of nuclear and uranium projects. To give one example (among many), the National Radioactive Waste Management Act dispossesses and disempowers Traditional Owners in many respects: the nomination of a site for a radioactive waste dump is valid even if Aboriginal owners were not consulted and did not give consent; the Act has sections which nullify State or Territory laws that protect archaeological or heritage values, including those which relate to Indigenous traditions; the Act curtails the application of Commonwealth laws including the Aboriginal and Torres Strait Islander Heritage Protection Act 1984 and the Native Title Act 1993 in the important site-selection stage; and the Native Title Act 1993 is expressly overridden in relation to land acquisition for a radioactive waste dump. Indeed, this issue has been so poorly prosecuted that our groups maintain that there is a pressing need for the federal Parliament to pause the current National Radioactive Waste Management Facility process pending the findings of a dedicated inquiry that explores all available options for the management of Australia's existing holdings of radioactive waste.

Legislation banning nuclear power should also be retained because no-one could possibly have any confidence that a satisfactory solution would be found for the long-term management of streams of low-, intermediate- and high-level nuclear waste resulting from a nuclear power program. Decades-long efforts to establish a repository and store for Australia's low- and intermediate-level radioactive wastes continue to flounder and are currently subject to legal and Human Rights Commission complaints and challenges, initiated by Traditional Owners of the affected sites in South Australia. Globally, no country has an operating repository for high-level nuclear waste. The United States has a deep underground repository for long-lived intermediate-level waste (the only operating deep underground repository worldwide) but it was closed from 2014–17 following a chemical explosion in an underground waste barrel. Safety standards and regulatory oversight fell away sharply within the first decade of operation of the US repository – a sobering reminder of the challenge of safely managing dangerous nuclear waste for millennia.

Legislation banning nuclear power should also be retained because the introduction of nuclear power would delay and undermine the development of effective, economic energy and climate policies based on renewable energy sources and energy efficiency. A December 2018 report by CSIRO and the Australian Energy Market Operator (AEMO) found that the cost of power from small modular reactors would be more than twice as expensive as power from wind and solar PV with some storage costs included (two hours of battery storage or six hours of pumped hydro storage). At the 29 August 2019 hearing of this inquiry, the AEMO foreshadowed the findings of its upcoming report. Alex Wonhas, AEMO's chief system design and engineering officer, said:
"What we find today at current technology cost is that unfirmed renewables in the form of wind and solar are effectively the cheapest form of energy production. If we look at firmed renewables, for

example wind and solar firmed with pumped hydro energy storage, that cost, at current cost, is roughly comparable to new build gas or new build coal-fired generation. Given the learning rate effect that we have just discussed, our expectation is that renewables will further decrease in their cost, and therefore firmed renewables will well and truly become the lowest cost of generation for the NEM."

Our organisations agree with the January 2019 statement issued by the Climate Council, comprising Australia's leading climate scientists and other policy experts. The Climate Council argued that nuclear power reactors "are not appropriate for Australia and probably never will be" and further stated: *"Nuclear power stations are highly controversial, can't be built under existing law in any Australian state or territory, are a more expensive source of power than renewable energy, and present significant challenges in terms of the storage and transport of nuclear waste, and use of water".*

2. ENERGY AFFORDABILITY AND RELIABILITY, ECONOMIC FEASIBILITY

"Nuclear construction on-time and on-budget? It's essentially never happened."
– Andrew J. Wittmann, financial analyst with Robert W. Baird & Co., 2017.[1]

2.1 An Australian perspective

Even the Australian Nuclear Association acknowledges that nuclear power reactors could not be built without taxpayer subsidies. Thus the proposal to introduce nuclear power fails the test that has been established by Prime Minister Scott Morrison.

Nuclear power is far more expensive than existing energy sources, including renewables, and therefore could not possibly contribute to efforts to reduce power prices. On the contrary, nuclear power would undoubtedly result in higher prices and thus fails the second test that has been established by the Prime Minister.

Prime Minister Morrison cited the 2006 Switkowski report when providing a sceptical response to a question about the economic viability of nuclear power for Australia. Nuclear costs have increased dramatically since 2006 (a negative learning curve – as discussed below and as discussed by Dr. Switkowski at the 29 August 2019 hearing of this inquiry).

The 2006 Switkowski report estimated the cost of electricity from new reactors at A$40–65 per megawatt-hour (MWh). That is approximately one-quarter of current estimates. Lazard's November 2018 report on levelized costs of electricity gives these figures[2]:

- Nuclear: A$166–280/MWh (US$112–189)
- Wind: A$43–83/MWh (US$29–56)
- Utility-scale solar: A$55–68/MWh (US$36–46)
- Natural-gas combined-cycle: A$61–110/MWh (US$41–74)

In 2009, Dr. Switkowski said that the construction cost of a 1,000 MW power reactor Australia would be A$4–6 billion.[3] Again, that is approximately one-quarter of the current cost estimates for all reactors under construction in western Europe (and Scandinavia) and north America, with cost estimates of those reactors ranging from A$17.8–24 billion.

Peter Farley, a fellow of the Australian Institution of Engineers, wrote in early 2019:[4]
"As for nuclear the 2,200 MW Plant Vogtle [in the US] is costing US$25 billion plus financing costs, insurance and long term waste storage. For the full cost of US$30 billion, we could build 7,000 MW of wind, 7,000 MW of tracking solar, 10,000 MW of rooftop solar, 5,000MW of pumped hydro and 5,000 MW of batteries. That is why nuclear is irrelevant in Australia."

In its May 2016 Final Report, the South Australian Nuclear Fuel Cycle Royal Commission concluded: "Taking into account the South Australian energy market characteristics and the cost of building and

[1] https://www.bloomberg.com/news/articles/2017-02-13/toshiba-s-nuclear-reactor-mess-winds-back-to-a-louisiana-swamp
[2] https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf
[3] https://www.theaustralian.com.au/opinion/a-clean-and-green-way-to-fuel-the-nation/news-story/92aabe042acb3ef3ffdbdfacc65631bf
[4] https://reneweconomy.com.au/how-did-wind-and-solar-perform-in-the-recent-heat-wave-40479/

operating a range of nuclear power plants, the Commission has found it would not be commercially viable to develop a nuclear power plant in South Australia beyond 2030 under current market rules."[5]

The SA Nuclear Fuel Cycle Royal Commission was also sceptical about the prospects for small modular reactors (SMRs) in light of its economic analysis (see section 3.3 below). The Commission's Final Report identified numerous hurdles and uncertainties facing SMRs including:[6]

- SMRs have a relatively small electrical output, yet some costs including staffing may not decrease in proportion to the decreased output.
- SMRs have lower thermal efficiency than large reactors, which generally translates to higher fuel consumption and spent fuel volumes over the life of a reactor.
- SMR-specific safety analyses need to be undertaken to demonstrate their robustness, for example during seismic events.
- It is claimed that much of the SMR plant can be fabricated in a factory environment and transported to site for construction. However, it would be expensive to set up this facility and it would require multiple customers to commit to purchasing SMR plants to justify the investment.
- Reduced safety exclusion zones for small reactors have yet to be confirmed by regulators.
- Timescales and costs associated with the licensing process are still to be established.
- SMR designers need to raise the necessary funds to complete the development before a commercial trial of the developing designs can take place.
- Customers who are willing to take on first-of-a-kind technology risks must be secured.

2.2 Australian Energy Market Operator studies

According to a December 2018 report by the CSIRO and the Australian Energy Market Operator (AEMO), the cost of power from small modular reactors would be more than twice as expensive as power from wind and solar PV with some storage costs included (two hours of battery storage or six hours of pumped hydro storage).[7]

At the 29 August 2019 hearing of this inquiry, AEMO foreshadowed the findings of its forthcoming report. Alex Wonhas, AEMO's chief system design and engineering officer, told the Committee:[8]
"What we find today at current technology cost is that unfirmed renewables in the form of wind and solar are effectively the cheapest form of energy production. If we look at firmed renewables, for example wind and solar firmed with pumped hydro energy storage, that cost, at current cost, is roughly comparable to new build gas or new build coal-fired generation. Given the learning rate effect that we have just discussed, our expectation is that renewables will further decrease in their cost, and therefore firmed renewables will well and truly become the lowest cost of generation for the NEM."

Hopefully the next AEMO report will be completed in time for it to be considered by the Committee before concluding this inquiry.

2.3 Nuclear power's economics crisis

Supporters of nuclear power have issued any number of warnings[9] in recent years about nuclear power's "rapidly accelerating crisis"[10] and a "crisis that threatens the death of nuclear energy in the

[5] South Australian Nuclear Fuel Cycle Royal Commission Report, May 2016, http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf
[6] http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf
[7] https://www.csiro.au/~/media/News-releases/2018/renewables-cheapest-new-power/GenCost2018.pdf
[8] www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy/Public_Hearings

West"[11], while pondering what if anything might be salvaged from the "ashes of today's dying industry".[12]

Consider the following statements, many of them from nuclear industry insiders:

- "I don't think we're building any more nuclear plants in the United States. I don't think it's ever going to happen. They are too expensive to construct." – William Von Hoene, Senior Vice-President of Exelon (the largest operator of nuclear power plants in the US), 2018.[13]
- Nuclear power "just isn't economic, and it's not economic within a foreseeable time frame." – John Rowe, recently-retired CEO of Exelon, 2012.[14]
- "It's just hard to justify nuclear, really hard." – Jeffrey Immelt, General Electric's CEO, 2012.[15]
- "I don't think anybody's pretending you can take forward a new nuclear power station without some form of government underwriting or support." – Sir John Armitt, chair of the UK National Infrastructure Commission, 2018.[16]
- France's nuclear industry is in its "worst situation ever"[17], a former EDF director said in November 2016 – and the situation has worsened since then.[18]
- Nuclear power is "ridiculously expensive" and "uncompetitive" with solar. – Nobuo Tanaka, former executive director of the International Energy Agency, and former executive board member of the Japan Atomic Industrial Forum, 2018.[19]
- Compounding problems facing nuclear developers "add up to something of a crisis for the UK's nuclear new-build programme." – Tim Yeo, former Conservative parliamentarian and now a nuclear industry lobbyist, 2017.[20]
- "I don't think a CEO of a utility could in good conscience propose a nuclear-power reactor to his or her board of directors." – Alan Schriesheim, director emeritus of Argonne National Laboratory, 2014.[21]
- "New-build nuclear in the West is dead" due to "enormous costs, political and popular opposition, and regulatory uncertainty" – *Morningstar* market analysts Mark Barnett and Travis Miller, 2013[22]
- "The mooted nuclear renaissance has clearly stalled." – Steve Kidd, former World Nuclear Association executive, 2014.[23]
- "Nuclear power and solar photovoltaics both had their first recorded prices in 1956. Since then, the cost of nuclear power has gone up by a factor of three, and the cost of PV has dropped by a factor of 2,500." – J. Doyne Farmer, Oxford University economics professor, 2016.[24]

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[9] https://www.wiseinternational.org/nuclear-monitor/839/nuclear-power-crisis-or-it-merely-end
[10] http://www.environmentalprogress.org/big-news/2017/2/13/why-its-big-bet-on-westinghouse-nuclear-bankrupted-toshiba
[11] http://www.environmentalprogress.org/big-news/2017/2/16/nuclear-must-change-or-die
[12] https://thebreakthrough.org/index.php/voices/ted-nordhaus/the-end-of-the-nuclear-industry-as-we-know-it
[13] https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/041218-no-new-nuclear-units-will-be-built-in-us-due-to-high-cost-exelon-official
[14] https://www.forbes.com/sites/jeffmcmahon/2012/03/29/exelons-nuclear-guy-no-new-nukes/
[15] https://www.ft.com/content/60189878-d982-11e1-8529-00144feab49a
[16] https://www.theguardian.com/uk-news/2018/jul/10/nuclear-renewables-are-better-bet-ministers-told
[17] http://www.theguardian.com/environment/2016/nov/29/french-nuclear-power-worst-situation-ever-former-edf-director
[18] https://climatenewsnetwork.net/frances-nuclear-industry-struggles-on/
[19] http://www.asahi.com/ajw/articles/AJ201807240045.html
[20] www.telegraph.co.uk/business/2017/04/01/can-britains-nuclear-ambitions-avoid-meltdown/
[21] http://www.forbes.com/sites/jeffmcmahon/2014/12/09/another-giant-declares-nuclear-dead-in-fracking-america/
[22] https://www.forbes.com/sites/jeffmcmahon/2013/11/10/new-build-nuclear-is-dead-morningstar/
[23] https://www.neimagazine.com/opinion/opinionuranium-enrichment-whats-happening-today-4311115/
[24] https://www.popularmechanics.com/science/energy/a18818/can-us-nuclear-power-get-un-stuck/

Even the International Atomic Energy Agency (IAEA) – which is tasked with promoting nuclear power – said in a September 2018 report that global nuclear power capacity "risks shrinking in the coming decades as ageing reactors are retired and the industry struggles with reduced competitiveness".[25] The IAEA's estimates for global nuclear power capacity in 2030 are 36% lower than the same estimates in 2010, the year before the Fukushima disaster.[26]

China is the only country with a significant nuclear new-build program. But China's nuclear power program has stalled twice over the past decade – after the 2011 Fukushima disaster and again in late 2016.[27] The most likely outcome over the next decade is that a small number of new reactor projects will be approved each year in China, well short of previous projections and not nearly enough to match the decline in the rest of the world. Currently, 46 reactors account for 4.2% of national electricity generation, with another 11 under construction. China's efforts to develop fast-breeder reactor technology have been unsuccessful, with one long-delayed, poorly-performing prototype reactor[28] and another demonstration reactor in the early stages of construction. Former World Nuclear Association executive Steve Kidd noted in August 2018 that the growth of renewables in China "dwarf the nuclear expansion" and that "many of the negative factors which have affected nuclear programmes elsewhere in the world are now also equally applicable in China."[29]

With the ageing of the current reactor fleet, it is becoming increasingly unlikely that new reactors will match shut-downs over the coming decades:

- The International Energy Agency expects a "wave of retirements of ageing nuclear reactors" and an "unprecedented rate of decommissioning" – almost 200 reactor shut-downs between 2014 and 2040.[30]
- The International Atomic Energy Agency (IAEA) anticipates 320 gigawatts (GW) of retirements (more than 80% of the worldwide total) from 2017 to 2050.[31]
- Another IAEA report estimates up to 139 GW of permanent shut-downs from 2018–2030 (more than one-third of the worldwide total) and up to 186 GW of further shut-downs from 2030–2050.[32]
- The reference scenario in the 2017 edition of the World Nuclear Association's *Nuclear Fuel Report* has 140 reactors closing by 2035.[33]
- A 2017 *Nuclear Energy Insider* article estimates up to 200 permanent shut-downs over the next two decades.[34]

[25] https://www.iaea.org/newscenter/pressreleases/new-iaea-energy-projections-see-possible-shrinking-role-for-nuclear-power
[26] https://www.wiseinternational.org/nuclear-monitor/866/new-iaea-report-sees-possible-shrinking-role-nuclear-power
[27] https://wiseinternational.org/nuclear-monitor/871/china-rescue
[28] https://www.wiseinternational.org/nuclear-monitor/831/slow-death-fast-reactors
[29] http://www.neimagazine.com/opinion/opinionnuclear-in-china-where-is-it-heading-now-6275899/
[30] International Energy Agency, 2014, 'World Energy Outlook 2014 Factsheet', www.iea.org/media/news/2014/press/141112_WEO_FactSheet_Nuclear.pdf
[31] International Atomic Energy Agency, 28 July 2017, 'International Status and Prospects for Nuclear Power 2017: Report by the Director General', www.iaea.org/About/Policy/GC/GC61/GC61InfDocuments/English/gc61inf-8_en.pdf
[32] International Atomic Energy Agency, 2018, 'Energy, Electricity and Nuclear Power Estimates for the Period up to 2050: 2018 Edition', https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-1-38_web.pdf
[33] World Nuclear Association, 2017, 'The Nuclear Fuel Report', http://www.world-nuclear.org/our-association/publications/publications-for-sale/nuclear-fuel-report.aspx
[34] Karen Thomas, 25 Jan 2017, 'OECD expands decommissioning cost benchmarks ahead of closure surge', http://analysis.nuclearenergyinsider.com/oecd-expands-decommissioning-cost-benchmarks-ahead-closure-surge

2.4 Recent experience in the US and western Europe: new reactors cost A$17.8–24 billion each

The V.C. Summer project in South Carolina (two AP1000 reactors) was abandoned after the expenditure of at least A$13.4 billion (US$9 billion).[35] The project was initially estimated to cost A$17.1 billion (US$11.5 billion); when it was abandoned, the estimate was around A$37.2 billion (US$25 billion).[36] Largely as a result of the V.C. Summer disaster, Westinghouse filed for bankruptcy and its parent company Toshiba almost went bankrupt as well. Both companies have decided that they will no longer take on the huge risks associated with reactor construction projects.

The cost estimate for the Vogtle project in US state of Georgia (two AP1000 reactors) has doubled to A$40.2–44.6+ billion (US$27–30+ billion) and will increase further, and the project only survives because of multi-billion-dollar government bailouts.[37] In 2006, Westinghouse said it could build an AP1000 reactor for as little as A$2.0 billion (US$1.4 billion)[38] – 10 times lower than the current estimate for Vogtle.

In the UK, three of six proposed reactor projects have been abandoned (Moorside, Wylfa, Oldbury), two remain in limbo (Sizewell and Bradwell) and Hinkley Point C is at the early stages of construction. The estimated combined cost of the two EPR reactors at Hinkley Point, including finance costs, is A$48.0 billion (£26.7 billion – the EU's 2014 estimate of £24.5 billion[39] including finance, plus a £2.2 billion increase announced in July 2017[40]). A decade ago, the estimated construction cost for one EPR reactor in the UK was almost seven times lower at A$3.7 billion (£2.0 billion).[41]

The UK National Audit Office estimates that taxpayer subsidies for Hinkley Point – primarily in the form of a guaranteed payment of A$166/MWh (£92.5/MWh), indexed for inflation, for 35 years – will amount to A$55 billion[42], while other credible estimates put the figure as high as A$91 billion.[43]

Hitachi abandoned the Wylfa project in Wales after the estimated cost of the twin-reactor project had risen from A$28.0 billion to A$42.0 billion (¥2 trillion to ¥3 trillion).[44] Hitachi abandoned the project despite unprecedented offers from the UK government to take a one third equity stake in the project; to consider providing all of the required debt financing; and to consider providing a guarantee of a minimum payment per unit of electricity (expected to be about A$134/MWh (£75/MWh)).[45]

In France, one EPR reactor is under construction at Flamanville. It is seven years behind schedule and the estimated cost of A$17.8 billion (€10.9 billion) is more than three times the original estimate of A$5.4 billion (€3.3 billion).[46] The French Government plans to reduce nuclear power's share of electricity generation from approximately 75% to 50% by 2035.[47]

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35 https://www.worldnuclearreport.org/Toshiba-Westinghouse-The-End-of-New-build-for-the-Largest-Historic-Nuclear.html
36 https://www.nytimes.com/2017/07/31/climate/nuclear-power-project-canceled-in-south-carolina.html
37 https://www.wiseinternational.org/nuclear-monitor/867/vogtles-reprieve-snatching-defeat-jaws-defeat
38 https://www.nytimes.com/2006/07/16/magazine/16nuclear.html
39 http://europa.eu/rapid/press-release_IP-14-1093_en.htm
40 https://www.theguardian.com/uk-news/2017/jul/03/hinkley-point-c-is-22bn-over-budget-and-a-year-behind-schedule-edf-admits
41 https://energypost.eu/saga-hinkley-point-c-europes-key-nuclear-decision/
42 https://www.theguardian.com/uk-news/2016/jul/13/hinkley-point-c-cost-30bn-top-up-payments-nao-report
43 http://www.no2nuclearpower.org.uk/wp/wp-content/uploads/2017/09/Time-to-Cancel-HinkleyFinal.pdf
44 https://mainichi.jp/english/articles/20181225/p2a/00m/0na/011000c
45 https://www.gov.uk/government/speeches/statement-on-suspension-of-work-on-thewylfa-newyddnuclear-project
46 http://www.globalconstructionreview.com/news/frances-nuclear-regulator-finally-approves-flamanv/
47 https://wiseinternational.org/nuclear-monitor/870/french-president-announces-energy-roadmap

In Finland, one EPR reactor is under construction. It is 10 years behind schedule and the estimated cost of A$17.9 billion (€11 billion) is more than three times the original A$4.9 billion (€3 billion) estimate.[48]

2.5 'Generation IV' and small modular reactor economics

Generation IV nuclear concepts were considered and rejected by the 2015/16 South Australian Nuclear Fuel Cycle Royal Commission. The Royal Commission said in its final report:[49]
"[A]dvanced fast reactors and other innovative reactor designs are unlikely to be feasible or viable in the foreseeable future. The development of such a first-of-a-kind project in South Australia would have high commercial and technical risk. Although prototype and demonstration reactors are operating, there is no licensed, commercially proven design. Development to that point would require substantial capital investment. Moreover, electricity generated from such reactors has not been demonstrated to be cost competitive with current light water reactor designs."

Most small modular reactors under construction are significantly over-budget. The economics of small modular reactors are summarised in section 3 of this submission and discussed in detail in a separate submission by Friends of the Earth Australia (submission #36[50]).

Historical experience is not promising. Fast neutron reactors are neither new nor cheap. For example, the French Superphenix fast neutron reactor was promoted as the first commercial-scale fast breeder reactor in the world but the electricity it produced is estimated to have cost an astonishing US$1,330/MWh.[51] Japan will have wasted over A$20 billion on its failed Monju fast neutron reactor once decommissioning is complete (see Appendix 2).

2.6 Nuclear power's negative learning curve

It is a standard characteristic of technological development that unit costs decrease over time, as the industry gains experience. Yet nuclear power is subject to a 'negative learning curve' − it has become increasingly expensive over time.[52] Citigroup states:
"The capital cost of nuclear build has actually risen in recent decades in some developed markets, partly due to increased safety expenditure, and due to smaller construction programmes (i.e. lower economies of scale). Moreover the 'fixed cost' nature of nuclear generation in combination with its relatively high price (when back end liabilities are taken into account) also places the technology at a significant disadvantage; utilities are reluctant to enter into a very long term (20+ years of operation, and decades of aftercare provisioning) investment with almost no control over costs post commissioning, with the uncertainty and rates of change currently occurring in the energy mix."[53]

Even the large-scale, standardised French nuclear power program has been subject to a negative learning curve.[54] The problem of escalating costs is worsening with the massive cost blowouts associated with the EPR projects in France and Finland.

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48 https://www.worldnuclearreport.org/World-Nuclear-Industry-Status-Report-2018-HTML.html#lien21
49 http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf
50 https://www.aph.gov.au/DocumentStore.ashx?id=7a9318c0-aad6-405e-832f-66212a87d158&subId=669038
51 Salahodeen Abdul-Kafi, 30 March 2011, 'The Superphénix Fast-Breeder Reactor', http://large.stanford.edu/courses/2011/ph241/abdul-kafi1/
52 Joe Romm, 6 April 2011, 'Does nuclear power have a negative learning curve?', http://thinkprogress.org/romm/2011/04/06/207833/does-nuclear-power-have-a-negative-learning-curve/
53 www.businessinsider.com.au/5-charts-that-show-nuclear-is-declining-2013-10
54 Arnulf Grubler, September 2010, 'The costs of the French nuclear scale-up: A case of negative learning by doing', *Energy Policy*, Vol.38, Issue 9, pp.5174–5188, www.sciencedirect.com/science/article/pii/S0301421510003526

In 2009, an updated version of a 2003 MIT Interdisciplinary Study on the Future of Nuclear Power was published, stating:[55]
"The estimated cost of constructing a nuclear power plant has increased at a rate of 15% per year heading into the current economic downturn. This is based both on the cost of actual builds in Japan and Korea and on the projected cost of new plants planned for in the United States."

Note that these significant cost escalations were very much in evidence before the March 2011 Fukushima disaster.

The high capital costs of nuclear power make it vulnerable to interest rate rises, credit squeezes and construction delays. As the World Nuclear Association notes, "long construction periods will push up financing costs, and in the past they have done so spectacularly."[56]

Citigroup commented on three 'Corporate Killers' in a 2009 report:[57]
"Three of the risks faced by developers − Construction, Power Price, and Operational − are so large and variable that individually they could each bring even the largest utility company to its knees financially. This makes new nuclear a unique investment proposition for utility companies."

Thus Citigroup foreshadowed the bankruptcy filing of Westinghouse (and the near-bankruptcy of its parent company Toshiba), which resulted primarily from massive cost overruns at the V.C. Summer reactor project in South Carolina and the abandonment of that partially-completed project after the expenditure of at least A$13.4 billion (US$9 billion).

[55] http://web.mit.edu/nuclearpower/
[56] World Nuclear Association, 'The Economics of Nuclear Power', http://web.archive.org/web/20140212215105/www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/
[57] Citigroup, 9 Nov 2009, 'New Nuclear - the Economics Say No: UK Green Lights New Nuclear – Or Does It?', http://nonuclear.se/files/SEU27102.pdf

3. SMALL MODULAR REACTORS

3.1 Overview

A separate submission by Friends of the Earth Australia discusses small modular reactors (SMRs) in detail.[58] An overview is presented here.

It is generally accepted that no SMRs are in operation although there is a (mostly unsuccessful) history of small reactors being used for power generation and some small power reactors currently operate. Further, it is generally accepted that a small number of SMRs are under construction (four according to the IAEA; a couple more according to the World Nuclear Association). Those statements depend on definitions: it could be argued that no SMRs are under construction since none of the small reactors under construction are based on modular, factory construction.

There is a long history of small reactors being used for naval propulsion, but efforts to develop land-based SMRs have not been successful. Academic M.V. Ramana concludes an analysis of the history of SMRs as follows:[59]

"Sadly, the nuclear industry continues to practice selective remembrance and to push ideas that haven't worked. Once again, we see history repeating itself in today's claims for small reactors – that the demand will be large, that they will be cheap and quick to construct. But nothing in the history of small nuclear reactors suggests that they would be more economical than full-size ones. In fact, the record is pretty clear: Without exception, small reactors cost too much for the little electricity they produced, the result of both their low output and their poor performance. ... Worse, attempts to make them cheaper might end up exacerbating nuclear power's other problems: production of long-lived radioactive waste, linkage with nuclear weapons, and the occasional catastrophic accident."

Here is the list of SMRS under construction[60] (for the Russian floating power plant, construction is complete but operation has not yet commenced):

- Russia's floating power plant with twin ice-breaker-type reactors (2 x 35 MW). The primary purpose of the plant is to power fossil fuel mining operations in the Arctic.[61]
- Russia's RITM-200 icebreaker ships powered by twin reactors (2 x 50 MW). Two such ships are operating and a third is under construction. The vessels are intended for the Northern Sea Route along the Russian Arctic coast.
- Argentina's 32-MW CAREM PWR reactor (Argentina's national atomic energy agency claimed in 2014 that it was the first SMR in the world to be officially under construction).
- China's high-temperature gas-cooled reactor (twin reactors feeding a single turbine).
- China's ACPR50S demonstration reactor (50–60 MW). According to China's CGN: "The ACPR50S, designed for the marine environment as a floating nuclear power plant, will be used to provide stable, economical and green resources, such as electricity, heat and fresh water, for China's oilfield exploitation in the Bohai Sea and deep-water oil and gas development in the South China Sea."[62]

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[58] https://www.aph.gov.au/DocumentStore.ashx?id=7a9318c0-aad6-405e-832f-66212a87d158&subId=669038

[59] M.V. Ramana, 27 April 2015, 'The Forgotten History of Small Nuclear Reactors', https://spectrum.ieee.org/tech-history/heroic-failures/the-forgotten-history-of-small-nuclear-reactors

[60] World Nuclear Association, Jan 2019, 'Small Nuclear Power Reactors', http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

[61] Jan Haverkamp, 28 May 2018, 'World's first purpose-built floating nuclear plant Akademik Lomonosov reaches Murmansk', Nuclear Monitor #861, https://www.wiseinternational.org/nuclear-monitor/861/worlds-first-purpose-built-floating-nuclear-plant-akademik-lomonosov-reaches

[62] CGN, 'Small Modular Reactor', accessed 13 Feb 2019, http://en.cgnpc.com.cn/encgn/c100050/business_tt.shtml

The World Nuclear Association lists nine SMR projects "for near-term deployment – development well advanced"[63] but few if any of those projects will progress to construction.

Roughly half of the SMRs under construction are designed to facilitate access to fossil fuel resources in the Arctic, the South China Sea and elsewhere (Russia's floating power plant, Russia's RITM-200 icebreaker ships, and China's ACPR50S demonstration reactor).

There are many disturbing connections between SMR projects, weapons proliferation and militarism more generally (see sections 6–8 of the Friends of the Earth Australia submission[64]).

While there is a great deal of hype and rhetoric about SMRs from the nuclear industry and its enthusiasts, informed opinion is sceptical. For example:

- A 2014 report produced by *Nuclear Energy Insider*, drawing on interviews with more than 50 "leading specialists and decision makers", noted a "pervasive sense of pessimism" resulting from abandoned and scaled-back SMR programs.[65]
- A 2017 Lloyd's Register report was based on the insights of almost 600 professionals and experts from utilities, distributors, operators and equipment manufacturers.[66] The professionals and experts predict that SMRs have a "low likelihood of eventual take-up, and will have a minimal impact when they do arrive".[67]
- The UK's National Infrastructure Commission said in a 2018 report: "Smaller reactors are still at an early stage of development and their benefits remain speculative."[68]
- William Von Hoene, senior vice president at Exelon – the largest operator of nuclear power plants in the US – said last year: "Right now, the costs on the SMRs, in part because of the size and in part because of the security that's associated with any nuclear plant, are prohibitive."[69]
- Former World Nuclear Association executive Steve Kidd includes SMRs in a list of self-serving "myths" promoted by the nuclear industry. He states: "The jury is still out on SMRs, but unless the regulatory system in potential markets can be adapted to make their construction and operation much cheaper than for large LWRs [large light-water reactors], they are unlikely to become more than a niche product. Even if the costs of construction can be cut with series production, the potential O&M [operating and maintenance] costs are a concern. A substantial part of these are fixed, irrespective of the size of reactor."[70]

The SMR industry has suffered multiple set-backs:

- Babcock & Wilcox abandoned its mPower SMR project in the US despite receiving government funding of US$111 million.

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[63] World Nuclear Association, Jan 2019, 'Small Nuclear Power Reactors', http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

[64] https://www.aph.gov.au/DocumentStore.ashx?id=7a9318c0-aad6-405e-832f-66212a87d158&subId=669038

[65] Nuclear Energy Insider, 2014, "Small Modular Reactors: An industry in terminal decline or on the brink of a comeback?", http://1.nuclearenergyinsider.com/LP=362

[66] Lloyd's Register, February 2017, 'Technology Radar – A Nuclear Perspective: Executive summary', https://www.lr.org/en/latest-news/technology-radar-low-carbon/

[67] World Nuclear News, 9 Feb 2017, Nuclear more competitive than fossil fuels: report', http://www.world-nuclear-news.org/EE-Nuclear-more-competitive-than-fossil-fuels-report-09021702.html

[68] National Infrastructure Commission, July 2018, 'National Infrastructure Assessment', www.nic.org.uk/wp-content/uploads/CCS001_CCS0618917350-001_NIC-NIA_Accessible.pdf

[69] Steven Dolley, 12 April 2018, 'No new nuclear units will be built in US due to high cost: Exelon official', https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/041218-no-new-nuclear-units-will-be-built-in-us-due-to-high-cost-exelon-official

[70] Steve Kidd, 11 June 2015, 'Nuclear myths – is the industry also guilty?', www.neimagazine.com/opinion/opinionnuclear-myths-is-the-industry-also-guilty-4598343/

- Transatomic Power gave up on its molten salt reactor R&D in 2018.
- Westinghouse sharply reduced its investment in SMRs after failing to secure US government funding.
- China is building a demonstration high-temperature gas-cooled reactor (it is behind schedule and over-budget) but plans for 18 additional HTGR reactors at the same site have been "dropped" according to the World Nuclear Association.[71]
- MidAmerican Energy gave up on its plans for SMRs in Iowa after failing to secure legislation that would require rate-payers to part-pay construction costs.
- Rolls-Royce sharply reduced its SMR investment in the UK to "a handful of salaries"[72] and is threatening to abandon[73] its R&D altogether unless massive grants are provided by the British government.[74]
- TerraPower abandoned its plan for a prototype reactor in China due to restrictions placed on nuclear trade with China by the Trump administration.[75]
- The French government is in the process of winding up its planned 100–200 MW ASTRID demonstration fast reactor due to funding constraints (partly due to massive cost overruns with another small reactor) and lack of interest in the pursuit of fast reactor technology (see Appendix 2 for further details).

There is nothing in the history of small reactors that would inspire any confidence in the likelihood of a significant SMR industry developing now. Further, the history of a number of proposed SMR sub-types has also been a history of failure:

- Fast neutron reactors have a deeply troubled history (see Appendix 2).
- Nothing in the history of high-temperature gas-cooled reactors (HTGRs) suggests that they are likely to progress beyond the experimental stage (see Appendix 6).
- The history of molten salt reactors is uninspiring, and a great deal of R&D needs to be done. The French Institute for Radiological Protection and Nuclear Safety states that there "is no likelihood of even an experimental or prototype MSR … being built during the first half of this century" let alone a factory-based production chain churning out MSRs in large numbers.[76] In 2013, Transatomic Power was promising that its 'Waste-Annihilating Molten-Salt Reactor' would deliver safer nuclear power at half the price of power from conventional, large reactors.[77] By the end of 2018, the company had given up on its 'waste-annihilating' claims, run out of money, and been dissolved.[78]

[71] World Nuclear Association, 21 March 2016, 'First vessel installed in China's HTR-PM unit', http://www.world-nuclear-news.org/NN-First-vessel-installed-in-Chinas-HTR-PM-unit-2103164.html

[72] NucNet, 23 July 2018, 'Rolls-Royce 'Planning To Shut Down SMR Project Without Government Support', https://www.nucnet.org/news/rolls-royce-planning-to-shut-down-smr-project-without-government-support

[73] Adam Vaughan, 1 Oct 2018, 'Energy firms demand billions from UK taxpayer for mini reactors', https://www.theguardian.com/environment/2018/sep/30/energy-firms-demand-billions-from-uk-taxpayer-for-mini-reactors

[74] Steve Thomas et al., 2019, 'Prospects for Small Modular Reactors in the UK & Worldwide', https://www.nuclearconsult.com/wp/wp-content/uploads/2019/07/Prospects-for-SMRs-report-2.pdf

[75] Reuters, 2 Jan 2019, 'Bill Gates' nuclear venture hits snag amid U.S. restrictions on China deals: WSJ', https://www.reuters.com/article/us-terrapower-china/bill-gates-nuclear-venture-hits-snag-amid-us-restrictions-on-china-deals-wsj-idUSKCN1OV1S5

[76] IRSN, 2015, 'Review of Generation IV Nuclear Energy Systems', https://www.irsn.fr/EN/newsroom/News/Documents/IRSN_Report-GenIV_04-2015.pdf

[77] Kevin Bullis, 12 March 2013, 'Safer Nuclear Power, at Half the Price', http://www.technologyreview.com/news/512321/safer-nuclear-power-at-half-the-price/

[78] Nuclear Monitor #867, 15 Oct 2018, 'Transatomic Gen IV startup shuts down', https://wiseinternational.org/nuclear-monitor/867/nuclear-news-nuclear-monitor-867-15-october-2018

3.2 No-one wants to pay for SMRs

"The fact that a technology has not been deployed, which is not economically competitive and is seen by financiers as too risky to support is a market success, not a failure."[79]

No company, utility, consortium or national government is seriously considering building the massive supply chain that is the very essence of SMRs – mass, modular factory construction. Yet without that supply chain, SMRs will be expensive, bespoke curiosities.

In early 2019, Kevin Anderson, North American Project Director for Nuclear Energy Insider, said that there "is unprecedented growth in companies proposing design alternatives for the future of nuclear, but precious little progress in terms of market-ready solutions."[80] Anderson argued that it is time to convince investors that the SMR sector is ready for scale-up financing, but that this would not be easy: *"Even for those sympathetic, the collapse of projects such as V.C. Summer does little to convince financiers that this sector is mature and competent enough to deliver investable projects on time and at cost."*[81]

Dr. Ziggy Switkowski – who headed the Howard Government's nuclear review in 2006 – recently made a similar point. "Nobody's putting their money up'' to build SMRs, he noted, and thus "it is largely a debate for intellects and advocates because neither generators nor investors are interested because of the risk."[82] Dr. Switkowski also recently noted that no-one knows how a network of SMRs might work in Australia because no such network can be found "anywhere in the world at the moment".[83]

A 2018 US Department of Energy report states that about US$10 billion of government subsidies would be needed to deploy 6 GW of SMR capacity by 2035.[84] But there is no likelihood that the US government will subsidise the industry to that extent. To date, the US government has offered US$452 million to support private-sector SMR projects[85], of which US$111 million was wasted on the mPower project that was abandoned in 2017.[86]

Canadian Nuclear Laboratories has set the goal of siting a demonstration SMR at its Chalk River site by 2026. But serious discussions about paying for a demonstration SMR – let alone a fleet of SMRs – have not yet begun. The Canadian SMR Roadmap website simply states: "Appropriate risk sharing among governments, power utilities and industry will be necessary for SMR demonstration and deployment in Canada."[87]

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[79] Steve Thomas et al., 2019, 'Prospects for Small Modular Reactors in the UK & Worldwide', https://www.nuclearconsult.com/wp/wp-content/uploads/2019/07/Prospects-for-SMRs-report-2.pdf
[80] Nuclear Energy Insider, 2019, 'The time is now – build the investment case to scale SMR', https://www.nuclearenergyinsider.com/international-smr-advanced-reactor
[81] https://www.nuclearenergyinsider.com/international-smr-advanced-reactor
[82] https://www.afr.com/politics/federal/no-investment-appetite-for-nuclear-switkowski-20190805-p52dwv
[83] Public Hearing, 29 Aug 2019, 'Inquiry into the prerequisites for nuclear energy in Australia', https://www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy/Public_Hearings
[84] Kutak Rock and Scully Capital for DOE's Office of Nuclear Energy, Oct 2018, 'Examination of Federal Financial Assistance in the Renewable Energy Market: Implications and Opportunities for Commercial Deployment of Small Modular Reactors', https://www.energy.gov/ne/downloads/report-examination-federal-financial-assistance-renewable-energy-market
[85] www.energy.gov/articles/energy-department-announces-new-funding-opportunity-innovative-small-modular-reactors
[86] https://wiseinternational.org/nuclear-monitor/872-873/mpower-obituary
[87] https://smrroadmap.ca/

In 2018, the UK Government agreed to provide £56 million towards the development and licensing of advanced modular reactor designs and £32 million towards advanced manufacturing research.[88] This year, the UK Government announced that it may provide up to £18 million to a consortium to help build a demonstration SMR along with up to £45 million to be invested in the second phase of the Advanced Modular Reactor program.[89] But those government grants are small change: companies seeking to pursue SMR projects in the UK want several billion pounds from the government to build a prototype SMR. As noted earlier, Rolls-Royce sharply reduced its SMR investment in the UK to "a handful of salaries" and is threatening to abandon its R&D altogether unless massive subsidies are provided by the British government.

State-run SMR programs – in Argentina, China, Russia, and South Korea – might have a better chance of steady and significant funding, but to date the investments in SMRs have been minuscule compared to investments in other energy programs. South Korea won't build any of its domestically-designed SMART SMRs in South Korea ("this is not practical or economic" according to the World Nuclear Association[90]). South Korea's plan to export SMART technology to Saudi Arabia is problematic given the Kingdom's suspected interest in pursuing a weapons program[91], and in any case the project may be in trouble.[92]

China and Argentina hope to develop a large export market for their high-temperature and small pressurised water reactors, respectively, but so far all they can point to are partially-built demonstration reactors that have been subject to major cost overruns and delays.

3.3 Independent economic assessments

Prime Minister Scott Morrison has set two tests for nuclear power: it must be able to stand on its own feet without government subsidies, and it must reduce household power bills. There isn't the slightest chance that nuclear power (including SMRs) could pass either test.

Electricity from SMRs will almost certainly cost more than that from large reactors because of diseconomies of scale: a 250 MW SMR will generate 25 percent as much power as a 1,000 MW reactor, but it will require more than 25 percent of the material inputs and staffing, and other costs including waste management and decommissioning will be proportionally higher.

Diseconomies of scale are certain. Offsetting cost-saving features are speculative. For example it is difficult to assess the benefit of modular factory production since no such factories exist and questions would inevitably arise such as whether the market is sufficiently large to yield the potential benefits of factory-line production – and whether a significant market could be sustained for any length of time. Elements of modular factory production were attempted with the V.C. Summer AP1000 project in South Carolina yet this project was abandoned after the expenditure of at least A$13.4 billion (US$9 billion).[93]

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[88] Neil Ford, 18 July 2018, 'UK funding spurs advanced reactor R&D but application outlook needed', https://analysis.nuclearenergyinsider.com/uk-funding-spurs-advanced-reactor-rd-application-outlook-needed
[89] https://www.parliament.uk/business/publications/written-questions-answers-statements/written-statements/
[90] http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx
[91] https://www.wiseinternational.org/nuclear-monitor/800/small-modular-reactors-chicken-and-egg-situation
[92] Jung Suk-yee, 16 Nov 2018, 'Small Modular Reactor Export from S. Korea in Jeopardy', http://www.businesskorea.co.kr/news/articleView.html?idxno=26628
[93] Richard Korman, 1 Nov 2017 'Witness to the Origins of a Huge Nuclear Construction Flop', Engineering News-Record, https://www.enr.com/articles/43325-witness-to-the-origins-of-a-huge-nuclear-construction-flop

SMRs are "leading the way in cost" according to Tania Constable from the Minerals Council of Australia.[94] NSW Deputy Premier John Barilaro claims that SMRs "are becoming very affordable".[95] But despite this enthusiasm, independent economic assessments consistently find that electricity from SMRs will be more expensive than that from large reactors:

- A study by WSP / Parsons Brinckerhoff prepared for the 2015/16 South Australian Nuclear Fuel Cycle Royal Commission estimated costs of A$180–184 per megawatt-hour (MWh) for large light-water reactors, compared to A$198–225 for SMRs.[96]
- A December 2018 report by CSIRO and the Australian Energy Market Operator concluded that "solar and wind generation technologies are currently the lowest-cost ways to generate electricity for Australia, compared to any other new-build technology."[97] It found that electricity from SMRs would be more than twice as expensive as that from wind or solar power with storage costs included (two hours of battery storage or six hours of pumped hydro storage).
- A report by the consultancy firm Atkins for the UK Department for Business, Energy and Industrial Strategy found that electricity from the first SMR in the UK would be 30% more expensive than that from large reactors, because of diseconomies of scale and the costs of deploying first-of-a-kind technology.[98]
- A 2015 report by the International Energy Agency and the OECD Nuclear Energy Agency predicted that electricity from SMRs will be 50−100% more expensive than that from large reactors, although it holds out some hope that large-volume factory production could reduce costs.[99]
- An article by four pro-nuclear researchers from Carnegie Mellon University's Department of Engineering and Public Policy, published in 2018 in the *Proceedings of the National Academy of Science*, considered options for the development of an SMR industry in the US. They concluded that it would not be economically viable on a commercial basis and could only be progressed if the

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SCANA and Santee Cooper, 6 May 2014, Letter to CB&I and Westinghouse Electric Corporation, https://bloximages.newyork1.vip.townnews.com/postandcourier.com/content/tncms/assets/v3/editorial/9/81/981c2f5a-a52e-11e7-a8b9-bb32b93afb23/59ce6d9b7e835.pdf.pdf
Ray Henry / Associated Press, 26 July 2014, 'Promises of Easier Nuclear Construction Fall Short', http://abcnews.go.com/US/wireStory/promises-easier-nuclear-construction-fall-short-24725848
Andrew Brown, 27 Aug 2017, 'Early signs of 'incompetence at every level' went unheeded as South Carolina rushed toward 'sexy' nuclear future', http://www.postandcourier.com/business/early-signs-of-incompetence-at-every-level-went-unheeded-as/article_b47acd2c-89a5-11e7-830a-9364c7e7b71b.html

[94] https://www.dailytelegraph.com.au/news/opinion/heatwaves-proof-positive-australia-needs-nuclear/news-story/5ac56694a4c8d09ff10d810c4eb583d1

[95] https://www.tenterfieldstar.com.au/story/6289951/is-nuclear-power-an-energy-solution-that-could-come-to-the-south-coast/?cs=7

[96] WSP / Parsons Brinckerhoff, Feb 2016, 'Quantitative analysis and initial business case – establishing a nuclear power plant and systems in South Australia', http://nuclearrc.sa.gov.au/app/uploads/2016/05/WSP-Parsons-Brinckerhoff-Report.pdf

[97] Report: https://www.csiro.au/~/media/News-releases/2018/renewables-cheapest-new-power/GenCost2018.pdf
Media release: https://www.csiro.au/en/News/News-releases/2018/Annual-update-finds-renewables-are-cheapest-new-build-power

[98] Atkins, 21 July 2016, 'SMR Techno-Economic Assessment Project 1: Comprehensive Analysis and Assessment Techno-Economic Assessment, Final Report, Volume 1, For The Department of Energy and Climate Change', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/665197/TEA_Project_1_Vol_1_-_Comprehensive_Analysis_and_Assessment_SMRs.pdf

[99] International Energy Agency (IEA) and OECD Nuclear Energy Agency (NEA), 2015, 'Projected Costs of Generating Electricity':
Media release: https://www.iea.org/newsroom/news/2015/august/joint-iea-nea-report-details-plunge-in-costs-of-producing-electricity-from-renew.html
Executive Summary: https://www.iea.org/Textbase/npsum/ElecCost2015SUM.pdf
Full report: https://webstore.iea.org/projected-costs-of-generating-electricity-2015

industry received "several hundred billion dollars of direct and indirect subsidies" over the next several decades.[100]

SMR enthusiasts envisage a large market emerging in the coming years. A frequently cited 2014 report by the UK National Nuclear Laboratory estimates 65–85 gigawatts (GW) of installed SMR capacity by 2035.[101] The estimate is highly ambitious given that no SMRs are operating, most or all of the small number of SMRs under construction have been subject to delays and cost overruns, and both governments and the private sector have been reluctant to invest.

The OECD's Nuclear Energy Agency is far more circumspect and realistic: it estimates <1 GW to 21 GW of installed worldwide SMR capacity by 2035[102] (by which time, at the current rate of installation, an additional 2500–3000 GW of new renewable capacity will have been installed).

The likelihood that SMRs will find anything more than a small, niche market is vanishingly small. Indeed, even the likelihood of a small, niche market is questionable. There was a wave of enthusiasm for SMRs in the late 1980s. Senator Peter McGauran, the Coalition's energy spokesperson, said in 1989: "You would know that new-generation reactors with maximum safety features are now coming into use. They are small (from 250–400 MW) and fully automated …"[103] However that wave of enthusiasm came and went without a single SMR being built anywhere in the world, and there is no reason to believe that the current wave of enthusiasm will be more productive.

Will Davis, a consultant to the American Nuclear Society, said in 2014 that the SMR "universe [is] rife with press releases, but devoid of new concrete".[15] The same can be said in 2019: few concrete plans and even fewer concrete pours. Artists' impressions of SMRs are proliferating[104] but there is little appetite – from industry or governments – to invest in SMR construction projects because of their high risks and uncertain outcomes.

3.4 Cost overruns on SMR projects

SMR projects will not be immune from the major cost overruns that have crippled large reactor projects. Indeed, cost overruns have already become the norm for SMR projects.

Estimated construction costs for Russia's floating nuclear power plant (with two 35-MW ice-breaker-type reactors) have increased more than four-fold to over US$10 billion / GW (US$740 million / 70 MW).[105] A 2016 OECD Nuclear Energy Agency report said that electricity produced by the Russian floating plant is expected to cost about US$200/MWh, with the high cost due to large staffing requirements, high fuel costs, and the resources required to maintain the barge and coastal infrastructure.[106]

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[100] M. Granger Morgan, Ahmed Abdulla, Michael J. Ford, and Michael Rath, July 2018 'US nuclear power: The vanishing low-carbon wedge', Proceedings of the National Academy of Science, https://www.pnas.org/content/115/28/7184

[101] UK National Nuclear Laboratory, December 2014, 'Small Modular Reactors (SMR) Feasibility Study', http://www.nnl.co.uk/media/1627/smr-feasibility-study-december-2014.pdf

[102] OECD Nuclear Energy Agency, 2016, 'Small Modular Reactors: Nuclear Energy Market Potential for Near-term Deployment', https://www.oecd-nea.org/ndd/pubs/2016/7213-smrs.pdf

[103] See p.34 in http://www.reasoninrevolt.net.au/objects/pdf/d2017.pdf

[104] https://wiseinternational.org/sites/default/files/NM872-873-final.pdf

[105] Charles Digges, 25 May 2015, 'New documents show cost of Russian floating nuclear power plant skyrockets', http://bellona.org/news/nuclear-issues/2015-05-new-documents-show-cost-russian-nuclear-power-plant-skyrockets

[106] OECD Nuclear Energy Agency, 2016, 'Small Modular Reactors: Nuclear Energy Market Potential for Near-term Deployment', https://www.oecd-nea.org/ndd/pubs/2016/7213-smrs.pdf

The CAREM (Central Argentina de Elementos Modulares) SMR under construction in Argentina illustrates the gap between SMR rhetoric and reality. In 2004, when the CAREM reactor was in the planning stage, Argentina's Bariloche Atomic Center estimated an overnight cost of US$1 billion / GW for an integrated 300 MW plant.[107] By April 2017, with construction underway, the cost estimate had soared to US$21.9 billion / GW (US$700 million / 32 MW).[108] The CAREM project is years behind schedule and costs will likely increase further.

Little information is available on the cost of China's demonstration 210 MW high-temperature gas-cooled reactor (HTGR). The World Nuclear Association states that the construction cost is US$6,000 / kW.[109] The estimated construction cost is reportedly about twice the initial cost estimate, with increases due to higher material and component costs, increases in labour costs, and increased costs associated with project delays.[110] China's Institute of Nuclear and New Energy Technology at Tsinghua University expects the cost of a scaled-up 655 MW HTGR to be 15-20% higher than the cost of a conventional 600 MW pressurised water reactor.[111] Further feasibility studies are underway in China but plans for 18 additional HTGRs at the same site as the demonstration plant have been "dropped" according to the World Nuclear Association.[112]

3.5 NuScale Power's economic claims

The US company NuScale Power is targeting a cost of US$65/MWh for its first SMR plant.[113]

But a study by WSP / Parsons Brinckerhoff prepared for the SA Nuclear Fuel Cycle Royal Commission estimated a levelised cost of A$225/MWh (US$155/MWh) based on the NuScale design.[114]

Thus WSP / Parsons Brinckerhoff's independent estimate is 2.4 times higher than NuScale's estimate.

NuScale's cost estimates should be regarded as promotional and will continue to drop – unless and until the company actually builds an SMR plant. A 2015 NuScale report estimated a levelized cost of US$98-$108/MWh.[115] By June 2018, the company said it is targeting a cost of just US$65/MWh for its first plant.[24] The company announced with some fanfare in 2018 that it had worked out how to make its SMRs almost 20% cheaper – by making them almost 20% bigger!

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107 Darío Delmastro, Marcelo Oscar Giménez et al., January 2004, 'CAREM concept: A competitive SMR', Conference Paper, Argentina's Bariloche Atomic Center, https://www.researchgate.net/publication/267579277_CAREM_concept_A_competitive_SMR

108 Andrew Baker, 17 April, 'Argentine nuclear reactor due to start up in 2020', https://www.bnamericas.com/en/news/electricpower/argentine-nuclear-reactor-due-to-start-up-in-2020/

109 World Nuclear Association, Feb 2019, 'Nuclear Power in China', http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

110 'China's plans to begin converting coal plants to walk away safe pebble bed nuclear starting in the 2020s', Dec 2016, http://www.nextbigfuture.com/2016/12/chinas-plans-to-begin-converting-coal.html

111 World Nuclear Association, Feb 2019, 'Nuclear Power in China', http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

112 World Nuclear Association, 21 March 2016, 'First vessel installed in China's HTR-PM unit', http://www.world-nuclear-news.org/NN-First-vessel-installed-in-Chinas-HTR-PM-unit-2103164.html

113 https://www.powermag.com/nuscale-boosts-smr-capacity-making-it-cost-competitive-with-other-technologies/?printmode=1

114 WSP / Parsons Brinckerhoff, Feb 2016, 'Quantitative analysis and initial business case – establishing a nuclear power plant and systems in South Australia', http://nuclearrc.sa.gov.au/app/uploads/2016/05/WSP-Parsons-Brinckerhoff-Report.pdf

115 Jay Surina (NuScale Chief Financial Officer), 20-21 August 2015, 'NuScale Plant Market: Competitiveness & Financeability', https://newsroom.nuscalepower.com/sites/nuscalepower.newshq.businesswire.com/files/press_release/additional/Jay_Surina_-_NuScale_Financial_Breakout_Session_0.pdf

Lazard estimates costs of US$112–189/MWh for electricity from large nuclear plants.[116] NuScale's claim that its electricity will be 2–3 times cheaper than that from large nuclear plants is implausible. And even if NuScale achieved costs of US$65/MWh, that would still be higher than Lazard's figures for wind power (US$29–56) and utility-scale solar (US$36–46).

Likewise, NuScale's construction cost estimate of US$4.2 billion / GW is implausible.[117] The latest cost estimate for the two AP1000 reactors under construction in the US state of Georgia (the only reactors under construction in the US) is US$12.3–13.6 billion / GW.[118] NuScale's target is just one-third of that cost – despite the unavoidable diseconomies of scale and despite the fact that every independent assessment concludes that SMRs will be more expensive to build (per GW) than large reactors. Further, modular factory-line production techniques were trialled with the AP1000 reactor project in South Carolina – a project that was abandoned after the expenditure of at least US$9 billion.

3.6 SMR Nuclear Technology's economic claims

In support of its claim that "it is likely that SMRs will be Australia's lowest-cost generation source", SMR Nuclear Technology Pty Ltd cites[119] a 2017 report[120] by the US Energy Innovation Reform Project (EIRP). According to SMR Nuclear Technology, the EIRP study "found that the average levelised cost of electricity (LCOE) from advanced reactors was US$60/MWh."

However the cost figures used in the EIRP paper are nothing more than the optimistic estimates of companies hoping to get 'advanced' reactor designs off the ground. Therefore the EIRP authors heavily qualified the report's findings:[121]
"There is inherent and significant uncertainty in projecting NOAK [nth-of-a-kind] costs from a group of companies that have not yet built a single commercial-scale demonstration reactor, let alone a first commercial plant. Without a commercial-scale plant as a reference, it is difficult to reliably estimate the costs of building out the manufacturing capacity needed to achieve the NOAK costs being reported; many questions still remain unanswered – what scale of investments will be needed to launch the supply chain; what type of capacity building will be needed for the supply chain, and so forth."

SMR Nuclear Technology's conclusions – that "it is likely that SMRs will be Australia's lowest-cost generation source" and that low costs are "likely to make them a game-changer in Australia" – have no more credibility than the company estimates used in the EIRP paper. The US$60/MWh figure cited by SMR Nuclear Technology is far lower than all independent estimates for SMRs such as the US$155/MWh (A$225/MWh) estimate in WSP / Parsons Brinckerhoff's study prepared for the SA Nuclear Fuel Cycle Royal Commission.[122]

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[116] https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

[117] https://www.powermag.com/nuscale-boosts-smr-capacity-making-it-cost-competitive-with-other-technologies/?printmode=1

[118] https://www.wiseinternational.org/nuclear-monitor/867/vogtles-reprieve-snatching-defeat-jaws-defeat

[119] SMR Nuclear Technology Pty Ltd, 2019, submission #39 to 'Inquiry into the prerequisites for nuclear energy in Australia', https://www.aph.gov.au/DocumentStore.ashx?id=7b830b3b-0a69-4850-aaf7-a1d8b9884bcb&subId=669049

[120] Energy Innovation Reform Project, 2017, 'What Will Advanced Nuclear Power Plants Cost? A Standardized Cost Analysis of Advanced Nuclear Technologies in Commercial Development', report prepared by the Energy Options Network, https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf

[121] ibid.

[122] WSP / Parsons Brinckerhoff, Feb 2016, 'Quantitative analysis and initial business case – establishing a nuclear power plant and systems in South Australia', http://nuclearrc.sa.gov.au/app/uploads/2016/05/WSP-Parsons-Brinckerhoff-Report.pdf

SMR Nuclear Technology's assertion that "nuclear costs are coming down due to simpler and standardised design; factory-based manufacturing; modularisation; shorter construction time and enhanced financing techniques" is at odds with all available evidence and it is at odds with Dr. Ziggy Switkowski's observation that "costs per kilowatt hour appear to grow with each new generation of technology".[123]

SMR Nuclear Technology claims that failing to repeal federal legislative bans against nuclear power would come at "great cost to the economy". However the introduction of nuclear power to Australia would most likely have resulted in the major cost overruns and delays that have crippled every reactor construction project in the US and western Europe over the past decade. Nor is it likely that the outcome would have been positive if Australia had instead pursued SMR options. Reflecting on experience in the UK over the past decade, Thomas et al. state:[124]
"There is every likelihood that, as with the previous nuclear renaissance, SMRs will be still born with few reactors built. This will mean that public money will again have been wasted on nuclear technology, but, as previously, the main cost will be the opportunity costs of the options not pursued and properly funded because resources have been pre-empted by the nuclear sector."

3.7 NuScale Power's safety claims

Claims made about the safety of SMRs are routinely overstated (please see section 9 in the separate Friends of the Earth Australia submission #36[125]).

Dr Edwin Lyman from the Union of Concerned Scientists (UCS) provides a reality check to claims made about NuScale Power's proposed SMRs:[126]

"As discussed in detail in my September 2013 report "Small Isn't Always Beautiful,"[127] UCS has safety and security concerns about small modular reactors in general and about the NuScale design in particular. SMR vendors are pushing the Nuclear Regulatory Commission (NRC) to weaken its regulations regarding operator staffing, security staffing, and emergency planning, based on highly optimistic assertions that their reactors will be significantly safer than larger reactors.

"NuScale raises issues because of its fundamental design: up to 12 reactor modules packed together in a swimming-pool type structure. The Fukushima disaster has shown the world the complexity of trying to manage multiple nuclear reactor accidents when crisis strikes, and it is far from obvious that the NuScale concept addresses this issue adequately. UCS also does not have confidence that the NRC's licensing processes will give appropriate weight to multi-unit safety issues. Unfortunately, earlier this month the NRC staff concluded that safety concerns associated with "multiunit core damage events" did not warrant further evaluation in its "Generic Issues" program, which could have resulted in additional regulatory requirements.

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[123] Public Hearing, 29 Aug 2019, 'Inquiry into the prerequisites for nuclear energy in Australia', https://www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy/Public_Hearings

[124] Steve Thomas et al., 2019, 'Prospects for Small Modular Reactors in the UK & Worldwide', https://www.nuclearconsult.com/wp/wp-content/uploads/2019/07/Prospects-for-SMRs-report-2.pdf

[125] https://www.aph.gov.au/DocumentStore.ashx?id=7a9318c0-aad6-405e-832f-66212a87d158&subId=669038

[126] Ed Lyman, 17 Dec 2013, 'Safety and Security Concerns about Small Modular Reactors: NuScale's Design', https://allthingsnuclear.org/elyman/safety-and-security-concerns-about-small-modular-reactors-nuscales-design

[127] Edwin Lyman, Sept 2013, 'Small Isn't Always Beautiful: Safety, Security, and Cost Concerns about Small Modular Reactors', https://www.ucsusa.org/sites/default/files/legacy/assets/documents/nuclear_power/small-isnt-always-beautiful.pdf

"Many of the safety concerns described in the UCS report have now been validated by a Powerpoint presentation that was recently included, perhaps inadvertently, in the many thousands of pages of documents that the NRC has released under a Freedom of Information Act request for documents related to the Fukushima accident. The Powerpoint presentation, entitled "Center for Nuclear Waste Regulatory Analyses: Support to the U.S. Nuclear Regulatory Commission Office of New Reactors"[128] (p. 479-529) and dated March 24, 2011, describes safety issues for SMRs such as

- *Potential fire and explosion hazards: below-grade facilities present unique challenges, such as smoke/fire behavior; life safety; design and operation of the HVAC system and removal of waste water.*
- *Potential flooding hazards: below-grade reactors and subsystems raise concerns with regard to hurricane storm surges, tsunami run-up and water infiltration into structures.*
- *Limited access for conducting inspections of pressure vessels and components that are crucial for containing radiation, such as welds, steam generators, bolted connections and valves.*

"The document also spells out safety concerns particular to the NuScale design, observing that the reactors and spent fuel are stored in the same structure and depend on the same pool for cooling; that the bioshield covering the reactors or even the reactors themselves could be displaced in a flood; that the cooling pool could become contaminated with debris or other substances during a flood; and that operation under both normal and accident conditions depends highly on proper operation of valves around the pressure vessel.

"This document underscores the fact that SMRs are novel designs that raise new safety issues, and much analysis and testing will be required in order to verify the vendors' safety claims. There is therefore no basis at the present time for the NRC to grant SMRs any special exemptions to its regulatory requirements, and the Department of Energy should take steps to ensure that its Technical Licensing Support program does not use taxpayer funds to endanger public health by undermining nuclear safety and security standards."

[128] Southwest Research Institute, 'Center for Nuclear Waste Regulatory Analyses: Support to the U.S. Nuclear Regulatory Commission Office of New Reactors', http://pbadupws.nrc.gov/docs/ML1327/ML13270A404.pdf

4. GENERATION IV REACTOR CONCEPTS

"Any plant you haven't built yet is always more efficient than the one you have built. This is obvious. They are all efficient when you haven't done anything on them, in the talking stage. Then they are all efficient, they are all cheap. They are all easy to build, and none have any problems."
– Admiral Hyman Rickover (who played a leading role in the development of the US nuclear industry), Congressional testimony, 1957.

Please also see relevant appendices:
Appendix 2: Fast neutron reactors (a.k.a. fast spectrum or fast breeder reactors)
Appendix 3: Integral Fast Reactors (IFRs)
Appendix 4: Fusion scientist debunks fusion power
Appendix 5: Thorium
Appendix 6: High-temperature Gas-Cooled Zombie Reactors

4.1 Overview

It seems that each generation must learn anew that 'next generation' or 'Generation IV' concepts are not new and not promising and that most might best be described as failed Generation I concepts. Recent history is littered with Generation IV and small modular reactor (SMR) corpses. The Generation mPower SMR project in the US was abandoned.[129] Transatomic Power gave up on its molten salt reactor R&D.[130] MidAmerican Energy gave up on its plans for SMRs in Iowa after failing to secure legislation that would require rate-payers to part-pay construction costs.[131] Westinghouse sharply reduced its investment in SMRs after failing to secure US government funding.[132] TerraPower abandoned its plan for a prototype fast neutron reactor in China due to restrictions placed on nuclear trade with China by the Trump administration[133] and is struggling to attract financing elsewhere. Plans to use 'integral fast reactors' for surplus plutonium disposition have been rejected in both the UK and the US.

In the US, even if all the private-sector Generation IV R&D funding was pooled together (an estimated US$1.3 billion[134]), it is unlikely that it would suffice to build a single prototype reactor. An article by pro-nuclear researchers from Carnegie Mellon University's Department of Engineering and Public Policy, published in the *Proceedings of the National Academy of Science* in July 2018, argues that no US advanced reactor design will be commercialised before mid-century and that purported benefits remain "speculative".[135]

[129] https://wiseinternational.org/nuclear-monitor/872-873/mpower-obituary
[130] https://wiseinternational.org/nuclear-monitor/867/nuclear-news-nuclear-monitor-867-15-october-2018
[131] https://pauldeaton.com/2013/06/04/iowa-pulls-the-plug-on-nuclear-power/
[132] http://www.world-nuclear-news.org/NN-Westinghouse-SMR-progress-slows-210214ST.html
[133] Reuters, 2 Jan 2019, 'Bill Gates' nuclear venture hits snag amid U.S. restrictions on China deals: WSJ', https://www.reuters.com/article/us-terrapower-china/bill-gates-nuclear-venture-hits-snag-amid-us-restrictions-on-china-deals-wsj-idUSKCN1OV1S5
[134] M. Granger Morgan, Ahmed Abdulla, Michael J. Ford, and Michael Rath, July 2018 'US nuclear power: The vanishing low-carbon wedge', Proceedings of the National Academy of Science, http://www.pnas.org/content/early/2018/06/26/1804655115
[135] ibid.

The US government has spent US$2 billion on Generation IV reactor R&D since the late 1990s "with very little to show for it" according to the Carnegie Mellon University researchers.[136] It is an option for the Australian government to pour billions into Generation IV R&D – but clearly it would not be a wise investment.

So-called Generation IV reactor concepts are diverse. Some are far from new – indeed most have been investigated for decades and have a troubled history. David Elliott – who worked initially with the UK Atomic Energy Authority and is now an Emeritus Professor at the Open University – has written a book about this troubled history.[137] In an article[138] discussing some themes taken up in his book, Elliot writes:

"While some nuclear enthusiasts hope that these Generation III reactors, like the EPR or its rivals, will be successful, there is also pressure to move on to new technology and so called Generation IV options, including liquid sodium-cooled fast neutron breeder reactors, helium-cooled high temperature reactors and thorium-fuelled molten salt reactors, at various scales. As I describe in my new book Nuclear Power: Past, Present and Future, many of them are in fact old ideas that were looked at in the early days and mostly abandoned. There were certainly problems with some of these early experimental reactors, some of them quite dramatic.

"Examples include the fire at the Simi Valley Sodium Reactor in 1959, and the explosion at the 3MW experimental SL-1 reactor at the US National Reactor Testing Site in Idaho in 1961, which killed three operators. Better known perhaps was and the core melt down of the Fermi Breeder reactor near Detroit in 1966. Sodium fires have been a major problem with many of the subsequent fast neutron reactor projects around the world, for example in France, Japan and Russia.

"For good or ill, ideas like this are back on the agenda, albeit in revised forms. … Fast neutron breeder reactors can produce new plutonium fuel from otherwise unused uranium-238 and may also be able to burn up some wastes, as in the Integral Fast Reactor concept and also the Traveling Wave Reactor variant. Molten Salt Reactors using thorium may be able to do this without producing plutonium or using liquid metals for cooling. Both approaches are being promoted, but both have problems, as was found in the early days. Certainly fast breeder reactors were subsequently mostly sidelined as expensive and unreliable. And as heightening nuclear weapons proliferation risks. The US gave up on them in the 1970s, France and the UK in the 1990s. Japan soldiered on, but has now abandoned its troubled Monju plant. For the moment it's mainly Russia that has continued, including with a molten lead cooled reactor, although India also has a fast reactor programme, linked to its thorium reactors plans.

"Thorium was used as a fuel for some reactors in some early experiments and is now being promoted again – there is more of it available globally than uranium. But there are problems. It isn't fissile, but neutrons, fast or slow, provided by uranium 235 or plutonium fission, can convert Thorium 232 into fissile U233. However, on the way to that, a very radioactive isotope, U232, is produced, which makes working with the fuel hard. Another isotope, U234 is also produced by neutron absorption. Ideally, to maximise U233 production, that should be avoided, but experts are apparently divided on whether this can be done effectively.

"The use of molten salts may help with some of these problems, perhaps making it easier to play with the nuclear chemistry and tap off unwanted by-products, but it is far from proven technically or economically. The economics is certainly challenging."

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[136] M. Granger Morgan, Ahmed Abdulla, Michael J. Ford, and Michael Rath, July 2018 'US nuclear power: The vanishing low-carbon wedge', Proceedings of the National Academy of Science, http://www.pnas.org/content/early/2018/06/26/1804655115
Media release, 2 July 2018, 'The vanishing nuclear industry', www.eurekalert.org/pub_releases/2018-07/coec-tvn062918.php
[137] David Elliott, May 2017, 'Nuclear Power: Past, Present and Future', Morgan & Claypool Publishers, http://bit.ly/2pIIX9Q
[138] David Elliott, 25 May 2017, 'Back to the future: old nukes for new', Nuclear Monitor #844, https://www.wiseinternational.org/nuclear-monitor/844/back-future-old-nukes-new

4.2 SA Nuclear Fuel Cycle Royal Commission

The SA Nuclear Fuel Cycle Royal Commission investigated claims made about Generation IV concepts and concluded in its May 2016 Final Report:[139]
"[A]dvanced fast reactors and other innovative reactor designs are unlikely to be feasible or viable in the foreseeable future. The development of such a first-of-a-kind project in South Australia would have high commercial and technical risk. Although prototype and demonstration reactors are operating, there is no licensed, commercially proven design. Development to that point would require substantial capital investment. Moreover, electricity generated from such reactors has not been demonstrated to be cost competitive with current light water reactor designs."

Little has changed since then – except the collapse of numerous Generation IV and SMR R&D projects.

4.3 Always decades away

Notwithstanding the history of (mostly failed) R&D projects, much work would need to be done to bring Generation IV concepts to commercial deployment.

The Generation IV International Forum states: "Depending on their respective degree of technical maturity, the first Generation IV systems are expected to be deployed commercially around 2030-2040."[140]

The Generation IV International Forum also states: "It will take at least two or three decades before the deployment of commercial Gen IV systems. In the meantime, a number of prototypes will need to be built and operated. The Gen IV concepts currently under investigation are not all on the same timeline and some might not even reach the stage of commercial exploitation."[141] It could be argued that most or all of them are unlikely to reach commercial-scale deployment.

The International Atomic Energy Agency states: "Experts expect that the first Generation IV fast reactor demonstration plants and prototypes will be in operation by 2030 to 2040."[142]

The World Nuclear Association noted in 2009 that "progress is seen as slow, and several potential designs have been undergoing evaluation on paper for many years."[143] The same could be said in 2019.

It should not be understood from the above statements that Generation IV systems will be commercialised in 2–3 decades. The point is that they are *always* 2–3 decades away. In general, R&D has not been promising and has been abandoned (either in the early stages, or following the failure of prototype reactors); R&D budgets are far too small to commercialise the concepts; and the pursuit of alternative energy sources has rightly been prioritised.

A 2015 report[144] by the French government's Institute for Radiological Protection and Nuclear Safety (IRSN) is of particular significance as it comes from a government which has invested heavily in nuclear

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[139] http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf
[140] www.gen-4.org/gif/jcms/c_9260/public
[141] www.gen-4.org/gif/jcms/c_41890/faq-2
[142] Peter Rickwood and Peter Kaiser, 1 March 2013, 'Fast Reactors Provide Sustainable Nuclear Power for "Thousands of Years"', www.iaea.org/newscenter/news/2013/fastreactors.html
[143] World Nuclear Association, 15 Dec 2009, 'Fast moves? Not exactly...', www.world-nuclear-news.org/NN_France_puts_into_future_nuclear_1512091.html

technology. IRSN is a government authority with approximately 1,790 staff under the joint authority of the Ministries of Defense, the Environment, Industry, Research, and Health.

The IRSN report 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."[145] The report says that for lead-cooled fast reactors and gas-cooled fast reactors systems, small prototypes might be built by mid-century. For molten salt reactors (MSR) and SuperCritical Water Reactors (SCWR) systems, there "is no likelihood of even an experimental or prototype MSR or SCWR being built during the first half of this century" and "it seems hard to imagine any reactor being built before the end of the century".

4.4 Purported benefits

It is doubtful whether the purported benefits of Generation IV reactors will be realised.

The French government's Institute for Radiological Protection and Nuclear Safety (IRSN) reviewed the six concepts prioritised by the Generation IV International Forum and concluded:[146]
"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 Reactor] ..."

Moreover the VHTR system could bring about significant safety improvements, the IRSN states, "but only by significantly limiting unit power".[147] The IRSN notes that it is difficult to thoroughly evaluate safety and radiation protection standards of Generation IV systems as some concepts have been partially tried and tested while others are still in the early stages of development.

The IRSN is unenthusiastic about research into transmutation of minor actinides (long-lived waste products in spent fuel), saying that "this option offers only a very slight advantage in terms of inventory reduction and geological waste repository volume when set against the induced safety and radiation protection constraints for fuel cycle facilities, reactors and transport." The IRSN notes that ASN, the French nuclear safety authority, has announced that minor actinide transmutation would not be a deciding factor in the choice of a future reactor system. Those factors partly explain the French government's recent decision to abandon the 100–200 MW ASTRID demonstration fast neutron reactor project.

Some Generation IV concepts promise major advantages, such as the potential to use long-lived nuclear waste and weapons-usable material (esp. plutonium) as reactor fuel. However, fast neutron reactor technology might more accurately be described as failed Generation I technology. The history of fast reactors has largely been one of extremely expensive, underperforming and accident-prone reactors which have contributed more to WMD proliferation problems than to their resolution. The troubled history of fast reactors is detailed in a report by the International Panel on Fissile Materials[148]

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[144] Institute for Radiological Protection and Nuclear Safety, 2015, 'Review of Generation IV Nuclear Energy Systems', www.irsn.fr/EN/newsroom/News/Pages/20150427_Generation-IV-nuclear-energy-systems-safety-potential-overview.aspx Direct download: www.irsn.fr/EN/newsroom/News/Documents/IRSN_Report-GenIV_04-2015.pdf
[145] ibid.
[146] ibid.
[147] ibid.
[148] International Panel on Fissile Materials, Feb 2010, 'Fast Breeder Reactor Programs: History and Status', www.ipfmlibrary.org/rr08.pdf

and in two appendices to this submission (2. Fast Neutron Reactors; 3. Integral Fast Reactors). Most of the countries that invested in fast reactor R&D have abandoned those efforts.

Regarding Generation IV concepts, Hirsch et al. state:[149]
"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."

Most importantly, whether Generation IV concepts deliver on their potential depends on a myriad of factors − not just the resolution of technical challenges. India's fast reactor / thorium program illustrates how badly things can go wrong, and it illustrates problems that cannot be solved with technical innovation. John Carlson, former Director-General of the Australian Safeguards and Non-proliferation Office, writes:[150]
"India has a plan to produce [weapons-grade] plutonium in fast breeder reactors for use as driver fuel in thorium reactors. This is problematic on non-proliferation and nuclear security grounds. Pakistan believes the real purpose of the fast breeder program is to produce plutonium for weapons (so this plan raises tensions between the two countries); and transport and use of weapons-grade plutonium in civil reactors presents a serious terrorism risk (weapons-grade material would be a priority target for seizure by terrorists)."

There is nothing 'advanced' about India's 'advanced' breeder / thorium reactor program. On the contrary, it is dangerous and irresponsible, all the more so since India refuses to allow IAEA safeguards inspections of its fast reactor / thorium program.

4.5 US Government Accountability Office Report

In 2015, the US Government Accountability Office (GAO) released a report on the status of small modular reactors (SMRs) and other new reactor concepts in the US that concluded:[151]
"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, although light water SMRs generally face fewer technical challenges than advanced reactors because of their similarities to the existing large LWR [light water] reactors. Depending on how they are resolved, these technical

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On the use of fast reactors in support of weapons production, see also Mycle Schneider, 2009, 'Fast Breeder Reactors in France', *Science and Global Security*, 17:36–53, www.princeton.edu/sgs/publications/sgs/archive/17-1-Schneider-FBR-France.pdf

[149] Helmut Hirsch, Oda Becker, Mycle Schneider and Antony Froggatt, April 2005, 'Nuclear Reactor Hazards: Ongoing Dangers of Operating Nuclear Technology in the 21st Century', report prepared for Greenpeace International, https://www.researchgate.net/publication/262630918

[150] John Carlson, 2014, first submission to Joint Standing Committee on Treaties, inquiry into Australia–India Nuclear Cooperation Agreement, Parliament of Australia, https://www.aph.gov.au/DocumentStore.ashx?id=79a1a29e-5691-4299-8923-06e633780d4b&subId=301365

See also: John Carlson, 2015, supplementary submission to Joint Standing Committee on Treaties, 'Suggested revisions to the text of 5 September 2014, as requested by JSCOT at the hearing of 9 February 2015', https://www.aph.gov.au/DocumentStore.ashx?id=242f5715-24fd-4b3e-8a4f-4c30651d1dc4&subId=301365

[151] US Government Accountability Office, July 2015, 'Nuclear Reactors: Status and challenges in development and deployment of new commercial concepts', GAO-15-652, www.gao.gov/assets/680/671686.pdf

challenges may result in higher-cost reactors than anticipated, making them less competitive with large LWRs 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, with costs up to $1 billion to $2 billion, to design and certify or license the reactor design, and there is an additional construction cost of several billion dollars more per power plant.
"Furthermore, the licensing process can have uncertainties associated with it, particularly for advanced reactor designs. A reactor designer would need to obtain investors or otherwise commit to this development cost years in advance of when the reactor design would be certified or available for licensing and construction, making demand (and customers) for the reactor uncertain. For example, the price of competing power production facilities may make a nuclear plant unattractive without favorable rates set by a public authority or long term prior purchase agreements, and accidents such as Fukushima as well as the ongoing need for a long-term solution for spent nuclear fuel may affect the public perception of reactor safety. These challenges will need to be addressed if the capabilities and diversification of energy sources that light water SMRs and advanced reactors can provide are to be realized."

Many of the same reasons explain the failure of the Next Generation Nuclear Plant (NGNP) Project. Under the Energy Policy Act of 2005, the US Department of Energy (DOE) was to deploy a prototype 'next generation' reactor using advanced technology to generate electricity and/or hydrogen by the end of fiscal year 2021. The project was initiated in 2005 but the DOE decided not to proceed with it in 2011, citing an impasse between the DOE and the NGNP Industry Alliance regarding cost-sharing arrangements.[152]

According to the GAO report, SMRs and new reactor concepts "face some common challenges such as long time frames and high costs associated with the shift from development to deployment − that is, in the construction of the first commercial reactors of a particular type."

Advanced reactor designers told the GAO that they have been challenged to find investors due to the lengthy timeframe, high costs, and uncertainty. Advanced reactor concepts face greater technical challenges than light water SMRs because of fundamental design differences.

4.6 False arguments advanced by the Australian government in support of participation in the Generation IV International Forum

Comments made in ANSTO's 'National Interest Analysis' (NIA)[153] justifying Australian participation in the Generation IV International Forum (GIF) include false and tenuous arguments, some of which are briefly discussed here.

The NIA asserts that participation in the (GIF) will further Australia's non-proliferation and nuclear safety objectives. No evidence is supplied to justify that tenuous assertion. There is much else that Australia could do – but is not doing – that would demonstrably further non-proliferation objectives, e.g.

- A ban on reprocessing of Australian Obligated Nuclear Materials (AONM).

[152] Nuclear Regulatory Commission, accessed 20 May 2019, 'Next Generation Nuclear Plant (NGNP)', https://www.nrc.gov/reactors/new-reactors/advanced/ngnp.html

[153] http://www.aph.gov.au/~/media/02%20Parliamentary%20Business/24%20Committees/244%20Joint%20Committees/JSCT/2017/Nuclear%20Energy/ATNIA%2013.pdf?la=en

- A reversal of the decision to permit uranium sales to countries that have not signed or ratified the NPT or who are not compliant with their NPT disarmament obligations.
- Refusing uranium sales to countries that refuse to sign or ratify the Comprehensive Test Ban Treaty.
- Constructively addressing the flaws and underfunding of the IAEA safeguards system.

Nuclear non-proliferation objectives would also be far better realised by Australian ratification of the UN Treaty on the Prohibition of Nuclear Weapons, rather than participation in GIF. Instead, Australia has spurned and undermined this important weapons ban treaty.

There is much else that Australia could do – but is not doing – that would demonstrably further safety objectives, including:

- Insisting that uranium customer countries establish a strong, independent regulatory regime (as opposed to the inadequate regulation in a number of customer countries, e.g. China[154], India[155], Russia[156], the US[157], Japan[158], South Korea[159], and others).
- Revisiting the decision to sell uranium to Ukraine in light of the ongoing conflict in that country and serious safety and regulatory inadequacies.[160]
- Giving effect to the recommendations of the United Nations system-wide study on the implications of the accident at the Fukushima Daiichi nuclear power plant (September 2011).[161]

The NIA states that ongoing participation in GIF will help Australia maintain its permanent position on the IAEA's 35-member Board of Governors. ANSTO routinely makes such arguments – in support of the construction of the OPAL reactor, in support of the development of nuclear power in Australia, and now in support of Australian participation in GIF. Australia has held a permanent position on the IAEA's Board of Governors for decades and there is no reason to believe that participation or non-participation in GIF will change that situation. Further, the importance of that permanent position is often overstated.

The NIA states that ongoing participation in GIF "will improve the Australian Government's awareness and understanding of nuclear energy developments throughout the region and around the world, and contribute to the ability of the Australian Nuclear Science and Technology Organisation (ANSTO) to continue to provide timely and comprehensive advice

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[154] Emma Graham-Harrison, 25 May 2015, 'China warned over 'insane' plans for new nuclear power plants', https://www.theguardian.com/world/2015/may/25/china-nuclear-power-plants-expansion-he-zuoxiu

[155] A. Gopalakrishnan, 13 Nov 2017, 'India Should Halt Further Expansion of its Nuclear Power Program', The Citizen, https://www.thecitizen.in/index.php/en/NewsDetail/index/2/12239/India-Should-Halt-Further-Expansion-of-its-Nuclear-Power-Program

[156] Vladimir Slivyak, 2014, 'Russian Nuclear Industry Overview', https://ecdru.files.wordpress.com/2017/04/russian-nuc-ind-overviewrgb.pdf

[157] Edwin Lyman, 29 Aug 2019, 'Aging nuclear plants, industry cost-cutting, and reduced safety oversight: a dangerous mix', https://thebulletin.org/2019/08/aging-nuclear-plants-industry-cost-cutting-and-reduced-safety-oversight-a-dangerous-mix/
Gregory Jaczko, 17 May 2019, 'I Oversaw the US Nuclear Power Industry. Now I Think It Should Be Banned', https://www.commondreams.org/views/2019/05/17/i-oversaw-us-nuclear-power-industry-now-i-think-it-should-be-banned

[158] Nuclear Monitor #800, 19 March 2015, 'Japan's 'nuclear village' reasserting control', www.wiseinternational.org/nuclear-monitor/800/japans-nuclear-village-reasserting-control

[159] Nuclear Monitor #844, 25 May 2017, 'South Korea's 'nuclear mafia'', www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-mafia

[160] L. Todd Wood, 30 March 2017, 'Ukrainian corruption casts nuclear pall over Europe', http://www.washingtontimes.com/news/2017/mar/30/ukrainian-corruption-casts-nuclear-pall-over-all-e/
Nuclear Monitor #832, 19 Oct 2016, 'Ukraine's nuclear power program going from bad to worse', https://www.wiseinternational.org/nuclear-monitor/832/ukraines-nuclear-power-program-going-bad-worse

[161] https://www.un.org/ga/search/view_doc.asp?symbol=SG/HLM/2011/1

on nuclear issues." Those arguments are tenuous: little or no information will be obtained through GIF participation that would not otherwise be available.

The NIA states that "Generation IV designs will use fuel more efficiently, reduce waste production, be economically competitive, and meet stringent standards of safety and proliferation resistance." Those false, promotional claims are refuted throughout this submission (sections 3–5, appendices 2–6).

4.7 Generation IV concepts and nuclear waste

These issues are discussed in section 5.5 of this submission.

4.8 Generation IV concepts and nuclear weapons proliferation

Advocates of every conceivable type of reactor claim that their preferred reactor type is proliferation-proof or proliferation-resistant.

A thorium enthusiast claims that thorium is "thoroughly useless for making nuclear weapons."[162] But the proliferation risks associated with thorium fuel cycles can be as bad as − or worse than − the risks associated with conventional uranium reactor technology.[163]

An enthusiast of integral fast reactors (IFR) claims they "cannot be used to generate weapons-grade material."[164] But IFRs *can* be used to produce plutonium for weapons – or at least they could be used to produce plutonium for weapons if they existed. 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."[165]

Fusion has yet to generate a single Watt of useful electricity but it has already contributed to proliferation problems. According to Khidhir Hamza, a senior nuclear scientist involved in Iraq's weapons program in the 1980s: "Iraq took full advantage of the IAEA's recommendation in the mid 1980s to start a plasma physics program for "peaceful" fusion research. We thought that buying a plasma focus device ... would provide an excellent cover for buying and learning about fast electronics technology, which could be used to trigger atomic bombs."[166]

Fusion scientist Dr. Daniel Jassby discusses the proliferation risks associated with fusion concepts in a 2017 article in the *Bulletin of the Atomic Scientists*.[167]

All existing and proposed reactor types and nuclear fuel cycles pose proliferation risks. The UK Royal Society notes: "There is no proliferation proof nuclear fuel cycle. The dual use risk of nuclear materials

162 Tim Dean, 16 March 2011, 'The greener nuclear alternative', https://www.abc.net.au/news/2011-03-16/thoriumdean/45178
163 'Thor-bores and uro-sceptics: thorium's friendly fire', Nuclear Monitor #801, 9 April 2015, https://www.wiseinternational.org/nuclear-monitor/801/thor-bores-and-uro-sceptics-thoriums-friendly-fire
164 Barry Brook, 9 June 2009, 'An inconvenient solution', The Australian, http://bravenewclimate.com/2009/06/11/an-inconvenient-solution/
165 George Stanford, 18 Sep 2010, 'IFR FaD 7 – Q&A on Integral Fast Reactors', http://bravenewclimate.com/2010/09/18/ifr-fad-7/
166 Khidhir Hamza, Sep/Oct 1998, 'Inside Saddam's Secret Nuclear Program', Bulletin of the Atomic Scientists, Vol. 54, No. 5, https://books.google.com.au/books?id=rwsAAAAAMBAJ
167 Daniel Jassby, 19 April 2017, 'Fusion reactors: Not what they're cracked up to be', Bulletin of the Atomic Scientists, https://thebulletin.org/2017/04/fusion-reactors-not-what-theyre-cracked-up-to-be/

and technology and in civil and military applications cannot be eliminated."[168] Likewise, John Carlson, former Director-General of the Australian Safeguards and Non-Proliferation Office, notes that "no presently known nuclear fuel cycle is completely proliferation proof".[169]

[168] UK Royal Society, 13 Oct 2011, 'Fuel cycle stewardship in a nuclear renaissance', http://royalsociety.org/policy/projects/nuclear-non-proliferation/report

[169] John Carlson, 2009, 'Introduction to the Concept of Proliferation Resistance', www.foe.org.au/sites/default/files/Carlson%20ASNO%20ICNND%20Prolif%20Resistance.doc or http://archive.foe.org.au/sites/default/files/Carlson%20ASNO%20ICNND%20Prolif%20Resistance.doc

5. WASTE MANAGEMENT, TRANSPORT AND STORAGE

5.1 Introduction

"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." – nuclear engineer Alan Parkinson.[170]

The 2006 Switkowski (UMPNER) report noted: "Establishing a nuclear power industry would substantially increase the volume of radioactive waste to be managed in Australia and require management of significant quantities of HLW [high-level nuclear waste]."[171]

In the mid- to late-2000s, Dr. Ziggy Switkowski, former Chair of the Board of the Australian Nuclear Science and Technology Organisation and head of the UMPNER Review, was promoting the construction of as many as 50 nuclear power reactors in Australia.[172] Over a 50-year lifespan, a 50-reactor (50-gigawatt) nuclear power program would:[173]

- be responsible for 1.8 billion tonnes of low-level radioactive tailings waste (assuming the uranium came from Olympic Dam).
- be responsible for 430,000 tonnes of depleted uranium waste.
- produce 75,000 tonnes of high-level nuclear waste (approx. 25,000 cubic metres).
- produce 750,000 cubic metres of low-level waste and intermediate-level waste.
- produce 750 tonnes of plutonium, enough for 75,000 nuclear weapons.

A demonstrated ability to manage Australia's current radioactive waste challenges would be necessary to establish confidence that Australia could manage the streams of radioactive and nuclear wastes arising from a nuclear power program.

However, Australia's current radioactive waste challenges are either being mismanaged or not managed at all:
1. Previous governments failed in their attempts to impose a national radioactive waste repository and store on unwilling communities in SA (1998–2004) and the NT (2005–2014).
2. The current push to establish a national radioactive waste repository and store in SA is strongly contested and aspects of the proposal are currently subject to legal challenges and a Human Rights Commission complaint, initiated by Traditional Owners of the targeted sites.

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[170] Alan Parkinson, 2002, 'Double standards with radioactive waste', *Australasian Science*, https://nuclear.foe.org.au/flawed-clean-up-of-maralinga/
[171] Switkowski Review, 2006, Uranium Mining, Processing and Nuclear Energy Review, http://pandora.nla.gov.au/tep/66043
[172] Ziggy Switkowski, 3 Dec 2009, 'Australia must add a dash of nuclear ambition to its energy agenda', www.smh.com.au/opinion/politics/australia-must-add-a-dash-of-nuclear-ambition-to-its-energy-agenda-20091201-k3pq.html
[173] Based primarily on figures in the UMPNER report. For information on the calculations for uranium tailings waste, see: 'There's No Nuclear Power Without Waste', 3 Dec 2010, http://web.archive.org/web/20130117002550/http://newmatilda.com/2010/12/03/theres-no-nuclear-power-without-waste

3. The management of radioactive tailings waste at past and current uranium mines has been deficient in many respects.[174] Cases in point here include continuing contamination concerns at both Mary Kathleen (Queensland) and Rum Jungle (NT).
4. At the former uranium mine at Radium Hill in SA, a radioactive waste repository "is not engineered to a standard consistent with current internationally accepted practice" according to a 2003 SA government audit.[175]
5. The Port Pirie uranium treatment plant in SA is still contaminated over 50 years after its closure.[176] It took a six-year community campaign just to get the site fenced off and to carry out a partial rehabilitation. As of July 2015, the SA government's website stated that "a long-term management strategy for the former site" is being developed.
6. SA regulators failed to detect Marathon Resource's illegal dumping of low-level radioactive waste in the Arkaroola Wilderness Sanctuary.[177] If not for the detective work of the managers of the Sanctuary, the illegal activities would never have been detected. The incident represents a serious failure of SA government regulation.
7. The 'clean-up' of nuclear waste at the Maralinga nuclear test site in the late 1990s was mismanaged and breached Australian and international standards regarding the disposal of long-lived radioactive waste.[178] Four scientists with first-hand information were highly critical of the 'clean up'.[179]
8. CSIRO faces a $30 million clean-up bill after barrels of radioactive waste at Woomera were found to be "deteriorating rapidly" and possibly leaking. An inspection found "significant rusting" of many of the 9,725 drums. An ARPANSA report found that the mixture of water and concentrated radioactive material inside some of the drums has the potential to produce explosive hydrogen gas.[180]

Former Liberal Party Senator Nick Minchin has commented on the difficulty of managing wastes from a nuclear power program:[181]
''My experience with dealing with just low level radioactive waste from our research reactor tells me it would be impossible to get any sort of consensus in this country around the management of the high level waste a nuclear reactor would produce."

Likewise, current Federal Resources Minister Senator Matt Canavan noted in June 2019:[182]
"We have been trying for 40 years to find a long-term repository for radioactive waste that is produced at Lucas Heights and some legacy waste we have from other activities. If we can't find a permanent home for low-level radioactive waste associated with nuclear medicines, we've got a pretty big challenge dealing with the high-level waste that would be produced by any energy facilities."

5.2 Global challenges with nuclear waste

There are no operating repositories for high-level nuclear waste anywhere in the world. The one and only deep underground repository for long-lived intermediate-level waste − the Waste Isolation Pilot

[174] See section 1.11 (p.74) in the joint submission to the SA Nuclear Fuel Cycle Royal Commission, https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf
[175] See section 3.2 (p.11) in the joint submission to the SA Nuclear Fuel Cycle Royal Commission, https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf
[176] Ibid.
[177] Ibid.
[178] Numerous articles on the flawed 'clean up' are posted at https://nuclear.foe.org.au/flawed-clean-up-of-maralinga/
[179] https://nuclear.foe.org.au/flawed-clean-up-of-maralinga/
[180] See the information posted at https://nuclear.foe.org.au/woomera/
[181] Brad Crouch, 21 May 2006, 'No nuke plant in 100 years', *The Advertiser*.
[182] Matthew Killoran, 21 June 2019, 'What a waste: Minister's question for nuclear inquiry', The Courier-Mail, https://www.couriermail.com.au/news/queensland/queensland-government/what-a-waste-ministers-question-for-nuclear-inquiry/news-story/b5dcfdcd0e81653c22137934d28a799b

Plant in the US – was shut for three years following a chemical explosion in an underground waste barrel.

Finland and Sweden are the countries most advanced with deep geological repository projects. However the planned high-level nuclear waste repository in Finland is years behind schedule. The planned high-level nuclear waste repository in Sweden has hit a snag with the Swedish Land and Environmental Court ruling that SKB's application can only be approved if *"SKB can provide documentation that shows the final storage facility complies in the long-term with requirements of the Environmental Code despite the uncertainties remaining on how the canisters protective capability is effected by a) corrosion due to reaction in oxygen-free water"* and four other issues regarding copper corrosion, including the influence of radiation on three additional variables. Amongst other things, SKB has not carried out corrosion tests with a canister containing spent fuel.[183]

Other countries operating nuclear power plants – including the US, the UK, Japan, South Korea, Germany, etc. – have not even established a site for a high-level nuclear waste repository, let alone commenced construction or operation. To give one example of a protracted, expensive and failed attempt to establish a high-level nuclear waste repository, plans for a repository at Yucca Mountain in Nevada were abandoned in 2009 – and current attempts to revive the project are being strongly contested. Over 20 years of work was put into the repository plan and well over A$10 billion wasted on the failed project. The repository plan was controversial and subject to scandals including one involving the falsification of safety data in relation to groundwater modeling. Studies found that Yucca Mountain could not meet the existing radiation protection standards in the long term and subsequent moves by the US Environmental Protection Agency to weaken radiation protection standards generated further controversy.[184]

A January 2019 report details the difficulties with high-level nuclear waste management in seven countries (Belgium, France, Japan, Sweden, Finland, the UK and the US) and serves as a useful overview of the serious problems that Australia has avoided by eschewing nuclear power.[185]

5.3 Long-term costs of high-level nuclear waste management

Estimated construction costs for high-level nuclear waste repositories are in the tens of billions of dollars and cost estimates have increased dramatically.[186] For example, the construction cost estimate in France was €25 billion (A$41.1 billion) as of 2016, well above the 2005 estimate of €13.5–16.5 billion (A$22.1–27.1 billion).[187]

The UK provides another example of dramatic escalations of cost estimates. Estimates of the clean-up costs for a range of civil and military UK nuclear sites including Sellafield have jumped from a 2005 estimate of £56 billion (A$101.5 billion) to over £100 billion (A$181.3 billion).[188]

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[183] Miles Goldstick, 29 Jan 2018, 'Swedish nuclear industry loses battle over repository but battle rages on', https://www.wiseinternational.org/nuclear-monitor/856/swedish-nuclear-industry-loses-battle-over-repository-battle-rages

[184] Nuclear Information & Resource Service, http://archives.nirs.us/radwaste/yucca/yuccahome.htm

[185] Robert Alvarez, Hideyuki Ban, Charles Laponche, Miles Goldstick, Pete Roche and Bertrand Thuillier, Jan 2019, 'Report - The Global Crisis of Nuclear Waste', https://www.greenpeace.fr/report-the-global-crisis-of-nuclear-waste/

[186] Ibid.

[187] World Nuclear Association, http://www.world-nuclear-news.org/WR-Minister-sets-benchmark-cost-for-French-repository-1801165.html

[188] Jonathan Leake, 9 Dec 2012, 'Nuclear cleanup to take 120 years and cost £100bn', https://www.thetimes.co.uk/article/nuclear-cleanup-to-take-120-years-and-cost-pound100bn-qmmczbh5rft

Operation of waste repositories adds many billions more to the costs. The US government estimates that to build a high-level nuclear waste repository and operate it for 150 years would cost US$96.2 billion (in 2007 dollars) (A$143 billion), a 67% increase on the 2001 estimate.[189]

The South Australian Nuclear Fuel Royal Commission estimated a similar figure: A$145 billion over 120 years for construction, operation and decommissioning of a high-level nuclear waste repository.[190]

5.4 Fire and chemical explosion in the world's only deep underground nuclear waste repository

No operating deep underground repositories for high-level nuclear waste exist, however there is one deep underground repository for long lived intermediate-level nuclear waste − the Waste Isolation Pilot Plant (WIPP) in the US state of New Mexico.

On 5 February 2014, a truck hauling salt caught fire at WIPP. Six workers were treated at the Carlsbad hospital for smoke inhalation, another seven were treated at the site, and 86 workers were evacuated. A March 2014 report by the US Department of Energy identified the root cause of the fire as the "failure to adequately recognize and mitigate the hazard regarding a fire in the underground." In 2011, the Defense Nuclear Facilities Safety Board, an independent advisory board, reported that WIPP "does not adequately address the fire hazards and risks associated with underground operations."[191]

In a separate incident, on 14 February 2014, an explosion (resulting from a heat-generating chemical reaction) ruptured one of the barrels stored underground at WIPP. This was followed by a failure of the filtration system meant to ensure that radiation did not reach the outside environment. Twenty-two workers were exposed to low-level radiation. WIPP was closed for three years. Direct and indirect costs associated with the accident are estimated at over US$2 billion (A$2.9 billion).[192]

A US government report blamed the barrel rupture and radiation release on the operator and regulator of WIPP, noting their "failure to fully understand, characterize, and control the radiological hazard ... compounded by degradation of key safety management programs and safety culture."[193]

A safety analysis conducted before WIPP opened predicted that one radiation release accident might occur every 200,000 years.[194] On the basis of real-world experience, i.e. empirical evidence, that estimate needs to be revised upwards to 10,000 radiation-release accidents over a 200,000-year period.

A troubling aspect of the WIPP problems is that complacency and cost-cutting set in just 10−15 years after the repository opened. Earl Potter, a lawyer who represented Westinghouse, WIPP's first operating contractor, said: "At the beginning, there was an almost fanatical attention to safety. I'm afraid the emphasis shifted to looking at how quickly and how inexpensively they could dispose of this

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[189] World Nuclear Association, 6 Aug 2008, 'Yucca Mountain cost estimate rises to $96 billion', http://www.world-nuclear-news.org/WR-Yucca_Mountain_cost_estimate_rises_to_96_billion_dollars-0608085.html
[190] Nuclear Fuel Cycle Royal Commission Report, May 2016, http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf
[191] 6 June 2014, 'Fire and leaks at the world's only deep geological waste repository', Nuclear Monitor #787, www.wiseinternational.org/node/4245
[192] https://www.latimes.com/nation/la-na-new-mexico-nuclear-dump-20160819-snap-story.html
[193] US Dept of Energy, Office of Environmental Management, April 2014, 'Accident Investigation Report: Phase 1: Radiological Release Event at the Waste Isolation Pilot Plant on February 14, 2014', http://energy.gov/em/downloads/radiological-release-accident-investigation-report
[194] Matthew Wald, 29 Oct 2014, 'In U.S. Cleanup Efforts, Accident at Nuclear Site Points to Cost of Lapses', www.nytimes.com/2014/10/30/us/in-us-cleanup-efforts-accident-at-nuclear-site-points-to-cost-of-lapses.html

waste."[195] Likewise, Rick Fuentes, president of the Carlsbad chapter of the United Steelworkers union, said: "In the early days, we had to prove to the stakeholders that we could operate this place safely for both people and the environment. After time, complacency set in. Money didn't get invested into the equipment and the things it should have."[196]

For more information on the WIPP accidents, see:
- Nuclear Monitor #801, 9 April 2015, 'One deep underground dump, one dud', https://www.wiseinternational.org/nuclear-monitor/801/one-deep-underground-dump-one-dud
- The Ecologist, 27 Nov 2014, 'New Mexico nuclear waste accident a 'horrific comedy of errors' that exposes deeper problems', https://theecologist.org/2014/nov/27/new-mexico-nuclear-waste-accident-horrific-comedy-errors-exposes-deeper-problems

5.5 Nuclear waste generated by small modular reactors and Generation IV reactors

Small modular reactors

Claims that small modular reactors (SMRs) based on conventional light-water reactor technology are advantageous with respect to nuclear waste have no logical or evidentiary basis.

The South Australian Nuclear Fuel Cycle Royal Commission said in its Final Report that "SMRs have lower thermal efficiency than large reactors, which generally translates to higher fuel consumption and spent fuel volumes over the life of a reactor."[197]

Likewise, a 2017 article by Princeton University researchers concludes: "Of the different major SMR designs under development, it seems none meets simultaneously the key challenges of costs, safety, waste, and proliferation facing nuclear power today and constraining its future growth. In most, if not all designs, it is likely that addressing one or more of these four problems will involve choices that make one or more of the other problems worse."[198]

One of the authors of the above-mentioned article, M.V. Ramana, notes in a different article that "a smaller reactor, at least the water-cooled reactors that are most likely to be built earliest, will produce more, not less, nuclear waste per unit of electricity they generate because of lower efficiencies."[199]

A 2016 European Commission document states:[200]
"At the current stage of development it cannot be assessed whether the decommissioning and waste management costs of SMRs will significantly differ from those of larger reactors. Due to the loss of economies of scale, the decommissioning and waste management unit costs of SMR will probably be higher than those of a large reactor (some analyses state that between two and three times higher)."

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[195] Patrick Malone, 14 Feb 2015, 'Repository's future uncertain, but New Mexico town still believes', www.santafenewmexican.com/special_reports/from_lanl_to_leak/repository-s-future-uncertain-but-new-mexico-town-still-believes/article_38b0e57b-2d4e-5476-b3f5-0cfe81ce94cc.html
[196] ibid.
[197] http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf
[198] M.V. Ramana and Zia Mian, Jan 2017, 'Small Modular Reactors and the Challenges of Nuclear Power', https://www.aps.org/units/fps/newsletters/201701/reactors.cfm
[199] M.V. Ramana, 23 June 2018, 'The future of nuclear power in the US is bleak', http://thehill.com/opinion/energy-environment/393717-the-future-of-nuclear-power-in-the-us-is-bleak
[200] European Commission, 4 April 2016, 'Commission Staff Working Document, Accompanying the document: Communication from the Commission, Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty for, the opinion of the European Economic and Social Committee', https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v10.pdf

Generation IV concepts and nuclear waste

Lindsay Krall and Allison Macfarlane have written an important article in the *Bulletin of the Atomic Scientists* debunking claims that certain Generation IV reactor concepts promise major advantages with respect to nuclear waste management.[201] Krall is a post-doctoral fellow at the George Washington University. Macfarlane is a professor at the same university, a former chair of the US Nuclear Regulatory Commission from July 2012 to December 2014, and a member of the Blue Ribbon Commission on America's Nuclear Future from 2010 to 2012.

Krall and Macfarlane focus on molten salt reactors and sodium-cooled fast reactors, and draw on the experiences of the US Experimental Breeder Reactor II and the US Molten Salt Reactor Experiment.

The article abstract notes that Generation IV developers and advocates "are receiving substantial funding on the pretense that extraordinary waste management benefits can be reaped through adoption of these technologies" yet "molten salt reactors and sodium-cooled fast reactors – due to the unusual chemical compositions of their fuels – will actually exacerbate spent fuel storage and disposal issues."

Krall and Macfarlane further state:
"The core propositions of non-traditional reactor proponents – improved economics, proliferation resistance, safety margins, and waste management – should be re-evaluated. The metrics used to support the waste management claims – i.e. reduced actinide mass and total radiotoxicity beyond 300 years – are insufficient to critically assess the short- and long-term safety, economics, and proliferation resistance of the proposed fuel cycles.
"Furthermore, the promised (albeit irrelevant) actinide reductions are only attainable given exceptional technological requirements, including commercial-scale spent fuel treatment, reprocessing, and conditioning facilities. These will create low- and intermediate-level waste streams destined for geologic disposal, in addition to the intrinsic high-level fission product waste that will also require conditioning and disposal.
"Before construction of non-traditional reactors begins, the economic implications of the back end of these non-traditional fuel cycles must be analyzed in detail; disposal costs may be unpalatable. The reprocessing/treatment and conditioning of the spent fuel will entail costs, as will storage and transportation of the chemically reactive fuels. These are in addition to the cost of managing high-activity operational wastes, e.g. those originating from molten salt reactor filter systems. Finally, decommissioning the reactors and processing their chemically reactive coolants represents a substantial undertaking and another source of non-traditional waste. ...
"Finally, treatment of spent fuels from non-traditional reactors, which by Energy Department precedent is only feasible through their respective (re)processing technologies, raises concerns over proliferation and fissile material diversion. Pyroprocessing and fluoride volatility-reductive extraction systems optimized for spent fuel treatment can – through minor changes to the chemical conditions – also extract plutonium (or uranium 233 bred from thorium). Separation from lethal fission products would eliminate the radiological barriers protecting the fuel from intruders seeking to obtain and purify fissile material. Accordingly, cost and risk assessments of predisposal spent fuel treatments must also account for proliferation safeguards.

[201] Lindsay Krall and Allison Macfarlane, 2018, 'Burning waste or playing with fire? Waste management considerations for non-traditional reactors', Bulletin of the Atomic Scientists, 74:5, pp.326-334, https://tandfonline.com/doi/10.1080/00963402.2018.1507791

"Radioactive waste cannot be "burned"; fission of actinides, the source of nuclear heat, inevitably generates fission products. Since some of these will be radiotoxic for thousands of years, these high-level wastes should be disposed of in stable waste forms and geologic repositories. But the waste estimates propagated by nuclear advocates account only for the bare mass of fission products, rather than that of the conditioned waste form and associated repository requirements.
"These estimates further assume that the efficiency of actinide fission will surge, but this actually relies on several rounds of recycling using immature reprocessing technologies. The low- and intermediate-level wastes that will be generated by these activities will also be destined for geologic disposal but have been neglected in the waste estimates. More important, reprocessing remains a security liability of dubious economic benefit, so the apparent need to adopt these technologies simply to prepare non-traditional spent fuels for storage and disposal is a major disadvantage relative to light water reactors. Theoretical burnups for fast and molten salt reactors are too low to justify the inflated back-end costs and risks, the latter of which may include a commercial path to proliferation.
"Reductions in spent fuel volume, longevity, and total radiotoxicity may be realized by breeding and burning fissile material in non-traditional reactors. But those relatively small reductions are of little value in repository planning, so utilization of these metrics is misleading to policy-makers and the general public. We urge policy-makers to critically assess non-traditional fuel cycles, including the feasibility of managing their unusual waste streams, any loopholes that could commit the American public to financing quasi-reprocessing operations, and the motivation to rapidly deploy these technologies."

<u>Pyroprocessing: the integral fast reactor waste fiasco</u>

In theory, integral fast reactors (IFRs) would consume nuclear waste and convert it into low-carbon electricity. In practice, the EBR-II (IFR) R&D program in Idaho has left a legacy of troublesome waste. This saga is detailed in a 2017 article[202] and a longer report[203] by the Union of Concerned Scientists' senior scientist Dr. Edwin Lyman, drawing on documents obtained under Freedom of Information legislation.

Lyman writes:[204]
"[P]yroprocessing has taken one potentially difficult form of nuclear waste and converted it into multiple challenging forms of nuclear waste. DOE has spent hundreds of millions of dollars only to magnify, rather than simplify, the waste problem. …
"The FOIA documents we obtained have revealed yet another DOE tale of vast sums of public money being wasted on an unproven technology that has fallen far short of the unrealistic projections that DOE used to sell the project …
"Everyone with an interest in pyroprocessing should reassess their views given the real-world problems experienced in implementing the technology over the last 20 years at INL. They should also note that the variant of the process being used to treat the EBR-II spent fuel is less complex than the process that would be needed to extract plutonium and other actinides to produce fresh fuel for fast reactors. In other words, the technology is a long way from being demonstrated as a practical approach for electricity production."

[202] Ed Lyman / Union of Concerned Scientists, 12 Aug 2017, 'The Pyroprocessing Files', http://allthingsnuclear.org/elyman/the-pyroprocessing-files
[203] Edwin Lyman, 2017, 'External Assessment of the U.S. Sodium-Bonded Spent Fuel Treatment Program', https://s3.amazonaws.com/ucs-documents/nuclear-power/Pyroprocessing/IAEA-CN-245-492%2Blyman%2Bfinal.pdf
[204] Ed Lyman / Union of Concerned Scientists, 12 Aug 2017, 'The Pyroprocessing Files', http://allthingsnuclear.org/elyman/the-pyroprocessing-files

5.6 Importing nuclear waste as a money-making venture and/or to fuel Generation IV reactors

The abandoned proposal for nuclear waste importation in SA

The 2015/16 SA Nuclear Fuel Cycle Royal Commission had a significant level of pro-nuclear bias[205] but nevertheless rejected most of the options it was asked to consider – uranium conversion and enrichment, nuclear fuel fabrication, conventional and Generation IV nuclear power reactors, and spent fuel reprocessing.

The Royal Commission did however recommend further consideration of a proposal to import vast amounts of nuclear waste (138,000 tonnes of high-level nuclear waste (spent nuclear fuel) and 390,000 cubic metres of intermediate-level waste) as a money-making venture. Following the Royal Commission, the government initiated a Citizens' Jury which voted strongly in opposition to the proposal.[206] The SA Liberal Party (then in Opposition, now in Government) announced its intention to campaign against the proposal. The Nick Xenophon Team also announced its opposition while the SA Greens had opposed the proposal from the start. Premier Jay Weatherill later said that the plan is "dead", there is "no foreseeable opportunity for this", and it is "not something that will be progressed by the Labor Party in Government".[207]

Thus the proposal has little or no political support in SA, and it never enjoyed public support. The statewide consultation process led by the government randomly surveyed over 6,000 South Australians and found 53% opposition to the proposal compared to 31% support.[208] A November 2016 poll commissioned by the *Sunday Mail* found 35% support for the nuclear dump plan among 1,298 respondents.

Opposition from Traditional Owners was overwhelming[209] and was a significant factor in the Citizen Jury's rejection of the proposal. The Jury's report said: "There is a lack of Aboriginal consent. We believe that the government should accept that the Elders have said NO and stop ignoring their opinions."[210]

While in office, Premier Weatherill said Traditional Owners should have a right of veto over any proposal to build nuclear waste storage or disposal facilities on their land – and he later wrote to then Prime Minister Turnbull suggesting that the same right of veto should apply to plans for a national radioactive waste facility in SA. The current federal plan is being contested in the courts and the Human Rights Commission by Traditional Owner representative groups for the two targeted regions.

[205] 'A Critique of the South Australian Nuclear Fuel Cycle Royal Commission', Dec 2015, https://nuclear.foe.org.au/critique-of-the-sa-nuclear-fuel-cycle-royal-commission/
'Bias of SA Nuclear Royal Commission finally exposed', 4 Nov 2016, http://reneweconomy.com.au/bias-sa-nuclear-royal-commission-finally-exposed-57819/
'SA Nuclear Royal Commission Is A Snow Job', 29 April 2016, http://reneweconomy.com.au/sa-nuclear-royal-commission-is-a-snow-job-18368/

[206] Citizens' Jury report: http://assets.yoursay.sa.gov.au/production/2016/11/06/07/20/56/26b5d85c-5e33-48a9-8eea-4c860386024f/final%20jury%20report.pdf

[207] http://indaily.com.au/news/politics/2017/06/07/theres-no-foreseeable-opportunity-jay-declares-nuke-dump-dead/

[208] http://assets.yoursay.sa.gov.au/production/2016/11/11/09/37/34/0c1d5954-9f04-4e50-9d95-ca3bfb7d1227/NFCRC%20CARA%20Community%20Views%20Report.pdf

[209] https://www.anfa.org.au/wp-content/uploads/2016/10/Traditional-Owner-statements-SA-dump-Oct2016.pdf

[210] http://assets.yoursay.sa.gov.au/production/2016/11/06/07/20/56/26b5d85c-5e33-48a9-8eea-4c860386024f/final%20jury%20report.pdf

In October 2017, a cross-party SA Parliament Joint Committee on the Findings of the Nuclear Fuel Cycle Royal Commission released its report with just one recommendation: "That the South Australian Government should not commit any further public funds to pursuing the proposal to establish a repository for the storage of nuclear waste in South Australia."[211]

Importing high-level nuclear waste for recycle in fast reactors

The Committee will likely receive submissions arguing that Australia should import high-level nuclear waste which could be converted into fuel for 'integral fast reactors' (IFRs – discussed in Appendix 3).

The SA Nuclear Fuel Cycle Royal Commission investigated such propositions and concluded:[212]
"[A]dvanced fast reactors and other innovative reactor designs are unlikely to be feasible or viable in the foreseeable future. The development of such a first-of-a-kind project in South Australia would have high commercial and technical risk. Although prototype and demonstration reactors are operating, there is no licensed, commercially proven design. Development to that point would require substantial capital investment. Moreover, electricity generated from such reactors has not been demonstrated to be cost competitive with current light water reactor designs."

Little has changed since the Royal Commission reported – except the collapse of a number of Generation IV R&D projects including Generation mPower, Transatomic Power, MidAmerican Energy's SMR plans, and TerraPower's plan for a demonstration fast reactor in China. Further, The UK government abandoned consideration of 'integral fast reactors' for plutonium disposition in March 2019 – and the US government did the same in 2015.

Creative accounting

The engineering of a positive economic case to proceed with the nuclear waste import plan was discussed by ABC journalist Stephen Long: "Would you believe me if I told you the report that the commission has solely relied on was co-authored by the president and vice president of an advocacy group for the development of international nuclear waste facilities?"[213]

Worse still, there was no peer review of the report that was co-authored by the president and vice president of an advocacy group for the development of international nuclear waste facilities.

Prof. Barbara Pocock, an economist at the University of South Australia, said: "All the economists who have replied to the analysis in that report have been critical of the fact that it is a 'one quote' situation. We haven't got a critical analysis, we haven't got a peer review of the analysis".[214]

The Royal Commission's economic claims were eventually subject to a peer review. The SA Parliament's Joint Committee commissioned a report by the Nuclear Economics Consulting Group which noted that the Royal Commission's economic analysis failed to consider important issues which "have significant serious potential to adversely impact the project and its commercial outcomes"; that assumptions about price were "overly optimistic" in which case "project profitability is seriously at risk"; that the 25% cost contingency for delays and blowouts was likely to be a significant underestimate; and that the

[211] http://www.parliament.sa.gov.au/Committees/Pages/Committees.aspx?CTId=2&CId=333
[212] http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf
[213] http://www.abc.net.au/news/2016-11-08/should-south-australia-be-storing-nuclear-waste-above-ground/8003156
[214] http://www.abc.net.au/news/2016-11-03/radioactive-waste-dump-would-boost-sa-economy-commission-hears/7991170

assumption the project would capture 50% of the available market had "little support or justification".[215]

South Australian economist Prof. Richard Blandy from Adelaide University, said: "The forecast profitability of the proposed nuclear dump rests on highly optimistic assumptions. Such a dump could easily lose money instead of being a bonanza."[216]

Likewise, a detailed report by the Australia Institute concluded that the business case for a nuclear waste storage facility in South Australia was exaggerated, that the project would be risky, and that an economic loss was well within the range of possible outcomes.[217]

Further information on the abandoned proposal for nuclear waste importation to SA

Submission to the SA Parliament's Joint Select Committee by Friends of the Earth, Conservation SA and Australian Conservation Foundation, July 2016, https://nuclear.foe.org.au/wp-content/uploads/SA-Joint-Select-Cttee-FoE-ACF-CCSA-final.pdf

5.7 Transportation of nuclear waste

Transport incidents and accidents are commonplace

A UK government database − RAdioactive Material Transport Event Database (RAMTED) − contains information on 1018 events from 1958 to 2011 (an average of 19 incidents each year) involving all forms of radioactive and nuclear materials, including waste.[218] Of the 38 incidents in the UK in 2011 alone, 11 involved irradiated nuclear fuel flasks (up from eight in 2010). One of those 11 events involved a low-impact collision.[219]

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[215] http://nuclear-economics.com/wp-content/uploads/2016/11/2016-11-11-NECG-Review-of-Jacobs-MCM-Report-for-SA-Parliament.pdf

[216] http://www.abc.net.au/news/2016-11-03/radioactive-waste-dump-would-boost-sa-economy-commission-hears/7991170
See also Prof. Blandy's submission to the Royal Commission: http://nuclearrc.sa.gov.au/app/uploads/2016/04/Blandy-Richard.pdf
See also https://indaily.com.au/news/business/analysis/2016/06/07/how-a-high-level-nuclear-waste-dump-could-lose-money/

[217] https://www.tai.org.au/content/digging-answers or direct download: https://www.tai.org.au/sites/default/files/P222A%20Digging%20for%20answers%20-%20SA%20Nuclear%20Royal%20Commission%20Submission%20FINAL.pdf

[218] Some recent annual reviews of transport incidents in the UK are posted at
http://webarchive.nationalarchives.gov.uk/20140722091854/www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/
Some earlier annual reviews are posted at:
http://webarchive.nationalarchives.gov.uk/20140722091854/www.hpa.org.uk/Publications/Radiation/HPARPDSeriesReports/
See also M.P. Harvey and A.L Jones, Aug 2012, 'HPA-CRCE-037 - Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2011 Review',
www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE037/

[219] M.P Harvey and A.L Jones (UK Health Protection Agency), August 2012, 'Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK − 2011 Review', commissioned by UK Office for Nuclear Regulation,
www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE037/

In a report on 806 recorded radioactive transport incidents in the UK from 1958−2004, Hughes et al. found that 111 involved 'residues inc. discharged INF flasks', 101 involved irradiated fuel, and 63 involved (other) radioactive wastes:[220]

MATERIAL TYPE *Source: Hughes et al, 2006*	**NUMBER OF EVENTS (806) FROM 1958−2004**	**PERCENTAGE**
Medical & industrial isotopes	376	46.7
Residues inc. discharged INF flasks	111	13.8
Irradiated fuel	101	12.5
Radiography sources	78	9.7
Radioactive wastes	63	7.8
Uranium ore concentrate	33	4
Other	44	5.5

There were 187 incidents during the shipment of irradiated nuclear fuel flasks from 1958−2004[221] − 23% of the total number of 806 recorded incidents. There is no evidence of safety improvements in the UK:

- In 2008, 18% of recorded incidents (7/39) involved irradiated nuclear fuel flasks.[222]
- In 2009, 24% of recorded incidents (8/33) involved irradiated nuclear fuel flasks.[223]
- In 2010, 27% of recorded incidents (8/30) involved irradiated nuclear fuel flasks.[224]
- In 2011, 29% of recorded incidents (11/38) involved irradiated nuclear fuel flasks.[225]

Transport incidents are also commonplace in France and presumably a comparable percentage involve nuclear wastes. In 2008, the French nuclear safety agency IRSN produced a report summarising radioactive transport accidents and incidents from 1999−2007.[226] The IRSN manages a database listing reported deviations, anomalies, incidents and accidents (known generically as "events") relating to transport. The database lists 901 events from 1999−2007 − on average 100 events annually or about two each week.

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[220] J.S. Hughes, D. Roberts, and S.J. Watson, July 2006, 'Review of Events Involving the Transport of Radioactive Materials in the UK, from 1958−2004, and their Radiological Consequences', http://webarchive.nationalarchives.gov.uk/20140714084352/www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947346295

[221] J.S. Hughes, D. Roberts, and S.J. Watson, July 2006, 'Review of Events Involving the Transport of Radioactive Materials in the UK, from 1958−2004, and their Radiological Consequences', http://webarchive.nationalarchives.gov.uk/20140714084352/www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947346295

[222] M. P. Harvey, Aug 2010, 'HPA-CRCE-003 - Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2009 Review', www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE003/

[223] ibid.

[224] M. P. Harvey and A. L. Jones, 2011, 'HPA-CRCE-024: Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2010 Review', www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE024/

[225] M.P. Harvey and A.L Jones, Aug 2012, 'HPA-CRCE-037 - Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2011 Review', www.hpa.org.uk/Publications/Radiation/CRCEScientificAndTechnicalReportSeries/HPACRCE037/

[226] IRSN (France), 21 Oct 2008, 'Information report: Incidents in transport of radioactive materials for civil use: IRSN draws lessons from events reported between 1999 and 2007',
www.irsn.fr/EN/publications/technical-publications/Documents/IRSN_ni_transports_analysis_20081021.pdf
www.irsn.fr/EN/Library/Documents/IRSN_ni_transports_analysis_20081021.pdf
www.irsn.fr/EN/Pages/home.aspx

In the US, in the eight years from 2005 to 2012, 72 incidents involving trucks carrying radioactive material on highways caused US$2.4 million in damage and one death, according to the Transportation Department's Pipeline and Hazardous Materials Safety Administration.[227]

Costs of accidents

Nuclear transport accidents involving spent nuclear fuel / high-level nuclear waste have the potential to be extraordinarily expensive. Dr. Marvin Resnikoff and Matt Lamb from Radioactive Waste Management Associates in New York City calculated 355−431 latent cancer fatalities attributable to a "maximum" hypothetical rail cask accident, compared to the US Department of Energy's estimate of 31 fatalities. Using the Department of Energy's model, they calculated that a severe truck cask accident could result in US$20 billion to US$36 billion in cleanup costs for an accident in an urban area, and a severe rail accident in an urban area could result in costs from US$145 billion to US$270 billion.[228]

An example of a million-dollar accident occurred in Roane County, Tennessee in 2004. A Bechtel-Jacobs truck spilled strontium-90 across nearly two miles of Highway 95. More than five hours after the spill occurred, authorities finally closed the road. Highway 95 remained closed for two days, after sections of the road were cleaned and re-paved. The Department of Energy said the clean-up bill would exceed US$1 million.[229]

Direct and indirect costs associated with the Feb. 2014 chemical explosion underground at the Waste Isolation Plant in New Mexico are estimated at over US$2 billion (A$2.9 billion).[230]

European nuclear waste transport scandal

In the late 1990s, a whistleblower supplied WISE-Paris, an environmental and energy NGO, with information which sparked a major controversy over frequent excessive radioactive contamination of waste containers, rail cars, and trucks.[231] Nuclear waste shipments from German nuclear reactor sites to reprocessing plants in the UK and France were banned, and transport within France was suspended, in the aftermath of the controversy.

WISE-Paris summarised the controversy in mid-1998:[232]
"There are two scandals, both unprecedented. The first lies in the fact that for 15 years the nuclear industry – power plants, transport companies, plutonium factories and nuclear safety institutes in France, Germany, Switzerland and the UK at least – have managed to hide the fact that the international transport regulations for spent fuel shipments have been constantly violated, up to levels exceeding several thousand times the limit. This is all the more stunning as the original

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[227] Anna M. Tinsley, 15 April 2012, 'Radioactive waste may soon travel on DFW highways', http://web.archive.org/web/20130504150446/www.star-telegram.com/2012/04/15/3884220/radioactive-waste-may-soon-travel.html
[228] 7 July 2000, www.state.nv.us/nucwaste/news2000/nn10719.htm
[229] www.nuclearfiles.org/menu/timeline/timeline_page.php?year=2004
[230] https://www.latimes.com/nation/la-na-new-mexico-nuclear-dump-20160819-snap-story.html
[231] WISE-Paris, Plutonium Investigation, No.6, May-June 1998,
www.wise-paris.org/index.html?/english/ournewsletter/6_7/contents.html
and
www.wise-paris.org/english/ournewsletter/6_7/no6_7.pdf
[232] www.wise-paris.org/index.html?/english/ournewsletter/6_7/editorial.html&/english/frame/menu.html
and
http://www.wise-paris.org/index.html?/english/ournewsletter/6_7/page4.html&/english/frame/menu.html&/english/frame/band.html

recommendation stems from the industry friendly, heavily pro-nuclear International Atomic Energy Agency (IAEA) in Vienna.
"The second scandal derives from the fact that the French nuclear safety authority DSIN has been aware of the problem since autumn 1997, agreed with the French nuclear industry representatives over the wording of a mere "cleanliness problem", and kept silent until a journalistic investigation brought the story to light. The safety authority neither informed its ministers nor its foreign counterparts and, of course, nor did it inform the public. Worse, when the story broke, the authority played the role of the tough transparent State control agency finally cleaning up ... without actually taking any kind of regulatory or disciplinary consequences, while downplaying health consequences and the persistent outrageous violation of regulations.
"The risk seems rather high that people have been exposed to significant levels of radiation over the period the contaminated transports have crossed countries. Worse, hot particles have been spread into the environment along rail tracks and roads. People might actually continue to get contaminated presently and for a long time to come."

French Environment Minister Dominique Voynet said:[233]
"Beyond the level of contamination, I'm shocked by the fact that as soon as one asks some simple questions to the operators, one realises that this has been going on for years, that the three companies questioned (EDF, Transnucléaire, COGEMA) were perfectly aware of it and that they have not said anything."

Some examples of accidents and incidents

Some examples of accidents and incidents involving the transport of radioactive waste are noted here:

In early 1998, it was revealed that "airtight" spent fuel storage canisters at ANSTO's Lucas Heights site had been infiltrated by water − 90 litres in one case − and corrosion had resulted. When canisters were retrieved for closer inspection, three accidents took place (2/3/98, 13/8/98, 1/2/99), all of them involving the dropping of canisters containing spent fuel while trying to transport them from the 'dry storage' site to another part of the Lucas Heights site. The public may never have learnt about those accidents if not for the fact that an ANSTO whistleblower told the local press. One of those accidents (1/2/99) subjected four ANSTO staff members to small radiation doses (up to 0.5 mSv).[234]

ANSTO has acknowledged that there are 1−2 accidents or 'incidents' every year involving the transportation of radioactive materials to and from the Lucas Heights reactor plant.[235] ANSTO provides no further detail but presumably some of the accidents and incidents involve waste materials.

In October 2014, a ship carrying radioactive waste which was set adrift in the North Sea after it caught fire led to the evacuation of the nearby Beatrice oil platform, part-owned by Ithaca Energy. The MV Parida was transporting six 500-litre drums of cemented radioactive waste from Scrabster in northern Scotland to Antwerp, Belgium, when the fire broke out in one of its funnels. The blaze was put out by the ship's crew. Meanwhile 52 workers were airlifted off the oil platform as a precaution in case the drifting MV Parida struck it. The ship was subsequently towed to a secure pier at the Port of Cromarty Firth by a commercial operator, despite the Aberdeen coastguard sending two emergency tugs to

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[233] http://www.wise-paris.org/english/ournewsletter/6_7/no6_7.pdf
[234] Sutherland Shire Environment Centre:
https://nuclearhistory.wordpress.com/2011/03/17/safety-problems-at-antso/
www.ssec.org.au/our_environment/issues_campaigns/nuclear/info_sheets/2002_sep_1.htm
[235] ANSTO, 2003, Submission to NSW Parliament's 'Joint Select Committee into the Transportation and Storage of Nuclear Waste'

assist. The cargo was reportedly undamaged. The waste was from the Dounreay experimental nuclear power plant.[236] Angus Campbell, the leader of the Western Isles Council, said the Parida incident highlighted the need for a second coastguard tug in the Minch. "A ship in similar circumstances on the west coast would be reliant on the Northern Isles-based ETV [emergency towing vessel] which would take a considerable amount of time to get to an incident in these waters."[237]

On 5 February 2014, a truck hauling salt caught fire at the Waste Isolation Pilot Plant (WIPP) in New Mexico. Six workers were treated at the Carlsbad hospital for smoke inhalation, another seven were treated at the site, and 86 workers were evacuated. A March 2014 report by the US Department of Energy identified the root cause of the fire as the "failure to adequately recognize and mitigate the hazard regarding a fire in the underground." In 2011, the Defense Nuclear Facilities Safety Board, an independent advisory board, reported that WIPP "does not adequately address the fire hazards and risks associated with underground operations."[238]

16 January 2014: A driver abandoned his stricken car at a level crossing moments before it was dragged 300 metres down a railway track by an empty nuclear waste train in the UK. The train is used to take spent nuclear fuel to Sellafield but, as it was returning to Cheshire, was empty.[239]

23 December 2013: A rail freight wagon carrying nuclear waste was derailed at a depot in Drancy, 3 km northeast of Paris. The wagon carried spent fuel from the Nogent nuclear power plant destined for AREVA's reprocessing plant at La Hague in Normandy. Although no leakage of radiation was measured at the accident location, the Nuclear Safety Authority (ASN) reported that subsequent testing by AREVA revealed a hotspot on the rail car that delivered a dose of 56 microsieverts.[240]

September 2002: A truck carrying nuclear waste from Idaho to the Waste Isolation Pilot Plant in New Mexico, USA, ran off Interstate 80 in Wyoming. The driver said he felt ill and attempted to pull over, but he blacked out before he made it to the roadside. The truck crossed the median, headed across the westbound lane and left the road. The accident was the second in less than two weeks. On Aug. 25, a truck bound for the WIPP plant near Carlsbad was hit by an alleged drunk driver. Nobody was injured and no contaminants were released in either accident, WIPP officials said.[241]

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[236] Andrew Snelling, 9 Oct 2014, 'Oil rig evacuated after radioactive fire', www.energynewspremium.net/StoryView.asp?storyID=826936500&section=General+News&sectionsource=s63&aspdsc=yes
NFLA / KIMO, 8 Oct 2014, 'NFLA and KIMO call for urgent inquiry into Parida nuclear waste transport fire off the Moray Firth', www.nuclearpolicy.info/docs/news/NFLA_KIMO_Parida_incident.pdf
West Highland Free Press 26 July 2014, www.whfp.com/2014/07/25/concern-over-nuclear-waste-shipments/
16 Oct 2014, 'Call for safety review following ship fire', www.fia.uk.com/en/information/details/index.cfm/call-for-safety-review-following-ship-fire
World Nuclear News, 8 Oct 2014, www.world-nuclear-news.org/WR-Dounreay-ready-to-assist-fire-investigation-08101401.html
[237] Herald, 30 July 2014 www.heraldscotland.com/news/home-news/plans-for-radioactive-waste-by-sea-are-criticised.24898732
[238] 6 June 2014, 'Fire and leaks at the world's only deep geological waste repository', Nuclear Monitor #787, www.wiseinternational.org/node/4245
[239] CORE Briefing, 15 Jan 2014, www.corecumbria.co.uk/newsapp/pressreleases/pressmain.asp?StrNewsID=331
www.lancasterguardian.co.uk/news/nuclear-waste-train-in-50mph-smash-1-6376671
Morning Star, 16 Jan 2014, www.morningstaronline.co.uk/a-e91c-Level-crossing-crash-exposes-dangers-of-nuclear-trains
Lancaster Guardian, 16 Jan 2014, www.lancasterguardian.co.uk/news/nuclear-waste-train-in-50mph-smash-1-6376671
[240] International Panel on Fissile Materials, 21 Jan 2014, http://fissilematerials.org/blog/2014/01/nuclear_train_accident_in.html
[241] AP, 9 Sept 2002, 'WIPP truck runs off highway in Wyoming', http://lubbockonline.com/stories/090902/upd_075-3941.shtml

A serious incident occurred in the UK in 2002.[242] AEA Technology was fined £250,000 for the incident during a 130-mile truck journey. A highly radioactive beam was emitted from a protective flask as it was driven across northern England and it was "pure good fortune" that no-one was dangerously contaminated, Leeds Crown Court was told. The problem arose when a plug was left off a specially-built 2.5-tonne container carrying radioactive material on a lorry. Staff used the wrong packaging equipment and failed to carry out essential safety checks before the radioactive cobalt-60 (decommissioned cancer treatment equipment) was transported from West Yorkshire to Cumbria. The court heard the 8mm-wide beam of radiation escaped through the bottom of the flask, pointing directly into the ground, throughout the three-hour road journey. Had the beam travelled horizontally, anyone within 280 metres would have been at risk of contamination from a beam of gamma rays up to 1000 times more powerful than a "very high dose rate". Radiation experts from the Health and Safety Executive said that anyone exposed to the beam could have exceeded the legal dose within seconds and suffered burns within minutes. One scientist estimated that someone standing a metre from the source and in the direct path of the rays would have been dead in two hours. The judge, Norman Jones, QC, said staff at the firm had acted in a "cavalier and somewhat indifferent" manner with a "degree of arrogance" towards their duties. He said the risk from the leak had been "considerable". In addition to the fine, he ordered the company to pay more than £150,000 in costs to the UK Health and Safety Executive.

3 February 1997 − High-level nuclear waste transport derails. A train carrying three casks with about 180 tons of high-level radioactive waste derailed near Apach (France). The waste was on its way from the nuclear power plant in Lingen (Germany) to Sellafield, UK, where it was to be reprocessed. The train was going at about 30 kilometers per hour, and the casks did not turn over. The incident was not a unique event. On 15 January 1997 a nuclear fuel cask derailed in front of the German nuclear power plant at Krümmel during a track change, and on 3 February 1997 the engine driver of a nuclear waste transport from Krümmel suffered from a faint.[243]

1976, Kentucky, USA: Six drums containing radioactive waste burst open after they rolled off tractor-trailer trucks in Ashfield, Kentucky, USA. Two drivers were slightly injured. When the highway was cleaned, checks indicated radioactivity.[244]

<u>More information on transport incidents and accidents</u>

Section 9.5 in this submission: 'Nuclear transport security issues'.

Section 3.8 in the August 2015 joint submission to the SA Nuclear Fuel Cycle Royal Commission by Friends of the Earth Australia, the Australian Conservation Foundation, and Conservation SA.[245]

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[242] UK Health and Safety Executive, 2006, 'Transport case prompts HSE reminder on the importance of radiation protection controls', www.hse.gov.uk/press/2006/e06017.htm
See also: 'Firm fined £250,000 over radioactive leak', The Scotsman, 21 February 2006, http://news.scotsman.com/topics.cfm?tid=112&id=267752006
See also: 'Toxic truck leak a radiation near-miss', 22 February 2006, www.theaustralian.news.com.au/common/story_page/0,5744,18231965%5E2703,00.html
[243] WISE News Communique #467, February 28, 1997
Die Tageszeitung (FRG) February 5, 1997
Greenpeace press release February 4, 1997
[244] Legislative Research Service Paper, Parliamentary Library, Canberra
[245] https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf

'Responsibility overboard: the shocking record of the company shipping nuclear waste to Australia', Natalie Wasley, 14 Aug 2018, Online Opinion, http://www.onlineopinion.com.au/view.asp?article=19892&page=0

6. HEALTH AND SAFETY

Please see the relevant sections in the joint submission to the SA Nuclear Fuel Cycle Royal Commission by Friends of the Earth Australia, the Australian Conservation Foundation, and Conservation SA:[246]

Section 1.8: Public and worker health hazards

- *Radiation and health*
- *Radon*
- *Leukemia*
- *Uranium, radiation and health*
- *Olympic Dam whistleblower*
- *Polonium exposure at Olympic Dam*
- *Uranium companies promote radiation junk science*
- *Case study: the Chernobyl death toll*

Section 1.11: Past uranium industry practices, including the exposure of children to radiation at disused uranium mines and processing plants in Australia.

Section 3.9 Lessons from accidents such as Fukushima

Section 3.10 Regulation

Section 3.13: Health and safety

- *History of accidents*
- *Safety challenges*
- *Safety of nuclear vs renewables*
- *Probabilistic risk assessments*
- *Attacks on nuclear plants*
- *Childhood leukemias near nuclear power stations*
- *Australia's track record*
- *Counterfeit, fraudulent and suspect items*

Since the joint submission for the Royal Commission was written, further evidence has emerged about the systemic corruption in South Korea's nuclear industry. This is important because South Korea would be one of the few potential suppliers of reactor technology to Australia (and it would be the preferred supplier in the view of the Australian Nuclear Association). For more information see Appendix 1 in this submission.

The Committee will likely receive submissions stating or implying that there is a threshold below which exposure to ionizing radiation is harmless. Such views are at odds with expert scientific opinion, including:

- The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) states in a 2010 report 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."[247]
- The 2006 report of the US National Academy of Sciences' Committee on the Biological Effects of Ionising Radiation (BEIR) 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."[248]

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[246] https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf

[247] UNSCEAR, 2010, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation on the Effects of Atomic Radiation 2010', www.unscear.org/docs/reports/2010/UNSCEAR_2010_Report_M.pdf

[248] US Committee on the Biological Effects of Ionising Radiation, US National Academy of Sciences, 2006, 'Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2',

Whether the relationship between radiation dose and health effects is linear at low doses is more contentious, but there is significant scientific support for a linear no-threshold (LNT) model, e.g. a report in the *Proceedings of the National Academy of Sciences* states: "Given that it is supported by experimentally grounded, quantifiable, biophysical arguments, a linear extrapolation of cancer risks from intermediate to very low doses currently appears to be the most appropriate methodology."[249]

While there is (and always will be) uncertainty with LNT at low doses and dose rates, it is important to note that the true risks may be *either higher or lower* than LNT − a point that needs emphasis and constant repetition because nuclear lobbyists routinely conflate uncertainty with zero risk. The BEIR report[250] 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." The BEIR report also states: "The committee recognizes that its risk estimates become more uncertain when applied to very low doses. Departures from a linear model at low doses, however, could either increase or decrease the risk per unit dose."

Death toll from the Chernobyl and Fukushima disasters

Claims that the Chernobyl death toll was <100 have no basis in scientific evidence. UN reports in 2005/06 estimated up to 4,000 eventual deaths among the higher-exposed Chernobyl populations (emergency workers from 1986−1987, evacuees and residents of the most contaminated areas) and an additional 5,000 deaths among populations exposed to lower doses in Belarus, the Russian Federation and Ukraine.[251] The estimated death toll rises further when populations beyond those three countries are included. For example, a study by Cardis et al. published in the *International Journal of Cancer* estimates 16,000 deaths.[252]

Likewise, claims that exposure to ionising radiation from the Fukushima disaster will not result in cancer deaths have no basis in scientific evidence. The World Health Organization states that for people in the most contaminated areas in Fukushima Prefecture, the estimated increased risk for all solid cancers will be around 4% in females exposed as infants; a 6% increased risk of breast cancer for females exposed as infants; a 7% increased risk of leukaemia for males exposed as infants; and for thyroid cancer among females exposed as infants, an increased risk of up to 70% (from a 0.75% lifetime risk up to 1.25%).[253]

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www.nap.edu/books/030909156X/html

[249] David Brenner et al., 2003, 'Cancer risks attributable to low doses of ionizing radiation: Assessing what we really know', Proceedings of the National Academy of Sciences, November 25, 2003, vol.100, no.24, pp.13761–13766, www.ncbi.nlm.nih.gov/pubmed/14610281

[250] US Committee on the Biological Effects of Ionising Radiation, US National Academy of Sciences, 2006, 'Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2', www.nap.edu/books/030909156X/html

[251] Chernobyl Forum, 2005, 'Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts', www.iaea.org/Publications/Booklets/Chernobyl/chernobyl.pdf
World Health Organization, 2006, www.who.int/mediacentre/news/releases/2006/pr20/en/index.html
www.who.int/ionizing_radiation/chernobyl/backgrounder/en/

[252] Cardis E, Krewski D, Boniol et al, 'Estimates of the Cancer Burden in Europe from Radioactive Fallout from the Chernobyl', International Journal of Cancer, Volume 119, Issue 6, pp.1224-1235, Published Online: 20 April 2006, www.ncbi.nlm.nih.gov/pubmed/16628547
http://onlinelibrary.wiley.com/doi/10.1002/ijc.22037/pdf

[253] WHO, 28 Feb 2013, 'Global report on Fukushima nuclear accident details health risks', www.who.int/mediacentre/news/releases/2013/fukushima_report_20130228/en/

Inadequate regulation

The Fukushima disaster resulted from grossly inadequate safety and regulatory standards in Japan's nuclear industry. Standards improved somewhat in the aftermath of the disaster but the collusive practices of Japan's 'nuclear village' are returning.[254] In other words, if lessons were learnt from the disaster, they are already being forgotten. This repeats the situation that followed the Chernobyl disaster − stronger safety and regulatory standards for a time, followed by complacency, cost-cutting, and governments ceding to industry calls to lower safety standards.

Inadequate regulation is evident in numerous countries with which Australia has uranium supply and nuclear cooperation agreements, e.g. China[255], India[256], Russia[257], the US[258], Japan[259], South Korea[260], and Ukraine.[261]

[254] Nuclear Monitor #800, 19 March 2015, 'Japan's 'nuclear village' reasserting control', www.wiseinternational.org/nuclear-monitor/800/japans-nuclear-village-reasserting-control

[255] Emma Graham-Harrison, 25 May 2015, 'China warned over 'insane' plans for new nuclear power plants', https://www.theguardian.com/world/2015/may/25/china-nuclear-power-plants-expansion-he-zuoxiu

[256] A. Gopalakrishnan, 13 Nov 2017, 'India Should Halt Further Expansion of its Nuclear Power Program', The Citizen, https://www.thecitizen.in/index.php/en/NewsDetail/index/2/12239/India-Should-Halt-Further-Expansion-of-its-Nuclear-Power-Program

[257] Vladimir Slivyak, 2014, 'Russian Nuclear Industry Overview', https://ecdru.files.wordpress.com/2017/04/russian-nuc-ind-overviewrgb.pdf

[258] Edwin Lyman, 29 Aug 2019, 'Aging nuclear plants, industry cost-cutting, and reduced safety oversight: a dangerous mix', https://thebulletin.org/2019/08/aging-nuclear-plants-industry-cost-cutting-and-reduced-safety-oversight-a-dangerous-mix/
Gregory Jaczko, 17 May 2019, 'I Oversaw the US Nuclear Power Industry. Now I Think It Should Be Banned', https://www.commondreams.org/views/2019/05/17/i-oversaw-us-nuclear-power-industry-now-i-think-it-should-be-banned

[259] Nuclear Monitor #800, 19 March 2015, 'Japan's 'nuclear village' reasserting control', www.wiseinternational.org/nuclear-monitor/800/japans-nuclear-village-reasserting-control

[260] Nuclear Monitor #844, 25 May 2017, 'South Korea's 'nuclear mafia'', www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-mafia

[261] L. Todd Wood, 30 March 2017, 'Ukrainian corruption casts nuclear pall over Europe', http://www.washingtontimes.com/news/2017/mar/30/ukrainian-corruption-casts-nuclear-pall-over-all-e/
Nuclear Monitor #832, 19 Oct 2016, 'Ukraine's nuclear power program going from bad to worse', https://www.wiseinternational.org/nuclear-monitor/832/ukraines-nuclear-power-program-going-bad-worse

7. ENVIRONMENTAL IMPACTS

Please see relevant sections in the joint submission to the SA Nuclear Fuel Cycle Royal Commission by Friends of the Earth Australia, the Australian Conservation Foundation, and Conservation SA:[262]

- Sections 1.10 and 1.11 (p.60ff) on the environmental impacts of the uranium mining industry.
- Section 2 (p.88–89) on depleted uranium waste.
- Section 2 (p.101–102) on spent nuclear fuel reprocessing.
- Section 3.11 (p.167ff) on greenhouse emissions.
- Section 3.11 (p.173–174) on nuclear winter.
- Section 3.11 (p.174–176) on climate change and nuclear hazards (nuclear power plants are vulnerable to threats which are being exacerbated by climate change).

See also section 5 in this submission regarding nuclear waste management, transport and storage.

8. COMMUNITY ENGAGEMENT, NATIONAL CONSENSUS

The introduction of nuclear power would require bipartisan support at the federal level – and bipartisan support in the relevant state/territory – over a period of five or more election cycles.

Currently there is a bipartisan political consensus that Australia should not introduce nuclear power and that federal legal prohibitions should be retained. A number of states have legislation banning nuclear power.

The last time one of the major parties promoted nuclear power was in the mid-2000s when Prime Minister John Howard and some other members of the Coalition government promoted nuclear power. During the 2007 election campaign, at least 22 Coalition candidates publicly distanced themselves from the government's pro-nuclear power policy. The pro-nuclear power policy was seen to be a liability and it was abandoned immediately after the election by the Coalition.

Public support for nuclear power in Australia has varied significantly over the past decade according to opinion polls, but has never reached 50% support. Part of the variation could be explained by polling questions, sample sizes etc. Some poll results are as follows:

- 2019: 44% support for nuclear power, 40% opposition.[263] (51% believe nuclear power would help lower power prices, 26% disagree.)
- 2015: 26.6% support for nuclear power in South Australia (level of opposition not surveyed).[264]
- 2013: 30% support for nuclear power, 53% opposition.[265]
- 2011 (after the Fukushima disaster): 34% support for nuclear power, 61% opposition (Roy Morgan poll).

Opposition to a locally-built nuclear power plant is clear:

- 2019: 28% "would be comfortable living close to a nuclear power plant", 60% would not.

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[262] https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf

[263] https://www.theguardian.com/australia-news/2019/jun/18/australians-support-for-nuclear-plants-rising-but-most-dont-want-to-live-near-one

[264] Paul Starick, 13 March 2015, 'Voters reject Premier Jay Weatherill's agenda to transform the state', www.adelaidenow.com.au/news/south-australia/voters-reject-premier-jay-weatherills-agenda-to-transform-the-state/story-fni6uo1m-1227262025901

[265] John McAneney et al., 14 Oct 2013, 'Why don't Australians see nuclear as a climate change solution?', http://theconversation.com/why-dont-australians-see-nuclear-as-a-climate-change-solution-19099

- 2011: 12% of Australians would support a nuclear plant being built in their local area, 73% would oppose it. (Morgan poll)
- 2006: 10% Australians would strongly support a nuclear plant being built in their local area, 55% would strongly oppose it. (Newspoll)

Opinion polls clearly show that renewables are far more popular than nuclear power:
- A 2019 survey of 1,960 Australians aged 18 years and older found that only 22% included nuclear power in their top three preferences, behind solar 76%, wind 58%, hydro 39% and power storage 29%.[266] Further, 59% of respondents put nuclear power in their bottom three preferences.[267]
- 2015: An IPSOS poll found support among Australians for solar power (78–87%) and wind power (72%) is far higher than support for coal (23%) and nuclear (26%).[268]
- 2015: When given the option of eight energy sources, 84% included solar in their top three, 69% included wind, 21% included gas and only 13% included nuclear.[269]
- 2013: Expanding the use of renewable energy sources (71%) was the most popular option to tackle climate change, followed by energy-efficient technologies (58%) and behavioural change (54%), with nuclear power (17.4%) a distant fourth.[270]

Regarding community engagement, nuclear lobbyists would need to convince Australians to accept the "non-negligible" risk of a catastrophic accident, to use the words of Dr. Ziggy Switkowski at the 29 August 2019 hearing of this inquiry.[271] Australians would need to be persuaded that a solution exists for nuclear waste management even though no country in the world has an operating repository for high-level nuclear waste, and the deep underground repository for intermediate-level waste in the US was shut for three years after safety and regulatory lapses resulted in a chemical explosion and the closure of the repository for three years.

Australians would also need to be persuaded that nuclear power makes sense in this country even though it clearly does not. Peter Farley, a fellow of the Australian Institution of Engineers, offered this comparison in January 2019:[272]
"As for nuclear the 2,200 MW Plant Vogtle is costing US$25 billion plus financing costs, insurance and long term waste storage. ... For the full cost of US$30 billion, we could build 7,000 MW of wind, 7,000 MW of tracking solar, 10,000 MW of rooftop solar, 5,000MW of pumped hydro and 5,000 MW of batteries. ... That is why nuclear is irrelevant in Australia. It has nothing to do with greenies, it's just about cost and reliability."

[266] Australia Institute, Sept 2019, 'Climate of the Nation 2019 Tracking Australia's attitudes towards climate change and energy', https://www.tai.org.au/sites/default/files/Climate%20of%20the%20Nation%202019%20%5BWEB%5D.pdf
[267] Katharine Murphy, 10 Sept 2019, 'Australians increasingly fear climate change-related drought and extinctions' https://www.theguardian.com/environment/2019/sep/10/australians-increasingly-fear-climate-change-related-drought-and-extinctions
[268] http://www.ipsos.com.au/Ipsos_docs/Solar-Report_2015/Ipsos-ARENA_SolarReport.pdf
[269] http://www.solarquotes.com.au/blog/climate-institute-poll-finds-australians-support-renewables/
[270] John McAneney et al., 14 Oct 2013, 'Why don't Australians see nuclear as a climate change solution?', http://theconversation.com/why-dont-australians-see-nuclear-as-a-climate-change-solution-19099
[271] www.aph.gov.au/Parliamentary_Business/Committees/House/Environment_and_Energy/Nuclearenergy/Public_Hearings
[272] https://reneweconomy.com.au/how-did-wind-and-solar-perform-in-the-recent-heat-wave-40479/

9. SECURITY IMPLICATIONS

Security risks associated with civil nuclear programs include the following:

- military strikes by nation-states on nuclear sites (primarily to prevent their use in weapons programs);
- attacks on or theft from nuclear facilities (or transport vehicles) by individuals or sub-national groups;
- nuclear theft and smuggling;
- sabotage / insider threats (e.g. the sabotage incident at Sellafield in 2000[273]).

9.1 Military strikes on nuclear plants

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

- Israel's destruction of a research reactor in Iraq in 1981.
- the United States' 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 weapons 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.

If and when nuclear-powered nations go to war, they will have to choose between i) shutting down their power reactors or ii) taking the risk of attacks potentially leading to widespread, large-scale dispersal of radioactive materials. Shutting down reactors would reduce risks but vulnerabilities would remain including reactor cores, waste stores and reprocessing plants (in those countries with reprocessing programs).

Nuclear physicist Richard Garwin poses these questions:[274]
"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."

9.2 Nuclear theft and smuggling

The IAEA summarises problems associated with nuclear theft, smuggling and other such illicit activities:[275]
"From January 1993 to December, 2013, a total of 2477 incidents were reported to the ITDB by participating States and some non-participating States. Of the 2477 confirmed incidents, 424 involved unauthorized possession and related criminal activities. Incidents included in this category involved illegal possession, movement or attempts to illegally trade in or use nuclear material or radioactive sources. Sixteen incidents in this category involved high enriched uranium (HEU) or plutonium. There were 664 incidents reported that involved the theft or loss of nuclear or other radioactive material and

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[273] 27 March 2000, 'Sabotage inquiry at Sellafield under way', www.irishtimes.com/news/sabotage-inquiry-at-sellafield-under-way-1.260139
[274] Richard L. Garwin, 2001, 'Can the World Do Without Nuclear Power?', www.solarpeace.ch/solarpeace/Download/20010409_Garwin_NuclearPowerArticle.pdf
[275] www-ns.iaea.org/security/itdb.asp

a total of 1337 cases involving other unauthorized activities, including the unauthorized disposal of radioactive materials or discovery of uncontrolled sources."

9.3 Insider threats

Matthew Bunn and Scott Sagan discuss the problem of insider threats in a paper − 'A Worst Practices Guide to Insider Threats: Lessons from Past Mistakes' − which forms part of a larger project on insider threats under the Global Nuclear Future project of the American Academy of Arts and Sciences.[276] One example they cite was the apparent insider sabotage of a diesel generator at the San Onofre nuclear plant in the United States in 2012. Another example was a 1982 incident in which an insider placed explosives directly on the steel pressure vessel head of a nuclear reactor in South Africa and detonated them − thankfully the plant had not yet begun operating. All known thefts of plutonium or highly enriched uranium appear to have been perpetrated by insiders or with the help of insiders. Similarly, most of the sabotage incidents that have occurred at nuclear facilities were perpetrated by insiders.

Bunn and Sagan look at past incidents caused by insiders and draw from them 10 lessons about what not to do. The lessons are as follows:
#1 Don't assume that serious insider problems are NIMO (Not In My Organization)
#2 Don't assume that background checks will solve the insider problem
#3 Don't assume that red flags will be read properly
#4 Don't assume that insider conspiracies are impossible
#5 Don't rely on single protection measures
#6 Don't assume that organizational culture and employee disgruntlement don't matter
#7 Don't forget that insiders may know about security measures and how to work around them
#8 Don't assume that security rules are followed
#9 Don't assume that only consciously malicious insider actions matter
#10 Don't focus only on prevention and miss opportunities for mitigation

9.4 Nuclear weapons proliferation

The weapons proliferation risks associated with civil nuclear programs are well understood and there is a long history of nation-states using civil nuclear programs as cover for weapons programs – five of the ten countries that have produced nuclear weapons did so under cover of a civil program, and power reactors have been used to produce plutonium for weapons in most or all of the other five nation-states (the 'declared' nuclear weapons states).[277]

The (civil) nuclear industry and its lobbyists have a long history of denying the connections between civil programs (including nuclear power programs) and weapons proliferation. However there has been a dramatic shift in recent years with a growing number of industry bodies and lobbyists acknowledging and even celebrating nuclear power–weapons connections.[278] They argue that weapons programs will be adversely affected unless further subsidies are made available to troubled nuclear power programs that make important contributions to weapons programs (personnel, materials, etc.).

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[276] Matthew Bunn and Scott Sagan, April 2014, 'A Worst Practices Guide to Insider Threats: Lessons from Past Mistakes', Occasional Paper, American Academy of Arts & Sciences, https://www.amacad.org/publication/worst-practices-guide-insider-threats-lessons-past-mistakes
[277] Nuclear Monitor #804, 28 May 2015, 'The myth of the peaceful atom', https://www.wiseinternational.org/nuclear-monitor/804/myth-peaceful-atom
[278] Andy Stirling and Phil Johnstone, 23 Oct 2018, ', A global picture of industrial interdependencies between civil and military nuclear infrastructures', Nuclear Monitor #868, https://www.wiseinternational.org/nuclear-monitor/868/global-picture-industrial-interdependencies-between-civil-and-military-nuclear

To give one example of this dramatic transformation, Michael Shellenberger from 'Environmental Progress', a pro-nuclear lobby group in the US, used to deny nuclear power–weapons connections, even claiming that "nuclear energy prevents the spread of nuclear weapons".[279] However in 2018 Shellenberger stated that "national security, having a weapons option, is often the most important factor in a state pursuing peaceful nuclear energy".

An analysis by Environmental Progress found that of the 26 nations that are building or are committed to build nuclear power plants, 23 have nuclear weapons, had weapons, or have shown interest in acquiring weapons.[280] "While those 23 nations clearly have motives other than national security for pursuing nuclear energy," Shellenberger wrote, "gaining weapons latency appears to be the difference-maker."[281]

Shellenberger also pointed to research[282] which found that 31 nations had the capacity to enrich uranium or reprocess plutonium, and that 71% of them created that capacity to give themselves weapons latency.

Shellenberger noted that "at least 20 nations sought nuclear power at least in part to give themselves the option of creating a nuclear weapon" – Argentina, Australia, Brazil, Egypt, France, Italy, India, Iran, Iraq, Israel, Japan, Libya, Norway, Romania, South Africa, Sweden, Switzerland, Taiwan, West Germany, Yugoslavia.[283]

Proliferation concerns would be lessened if the international safeguards system was rigorous and properly funded. Sadly it is neither, as discussed in section 2.12 of the joint submission to the SA Nuclear Fuel Cycle Royal Commission by Friends of the Earth Australia, the Australian Conservation Foundation, and Conservation SA.[284]

9.5 Nuclear transport security issues

Hirsch et al. summarise some of the security risks associated with the transport of nuclear materials:[285]
"During transport, radioactive substances are a potential target for terrorists. Of the numerous materials being shipped, the following are the most important:

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[279] Nuclear Monitor #865, 6 Sept 2018, 'Nuclear lobbyist Michael Shellenberger learns to love the bomb, goes down a rabbit hole', https://www.wiseinternational.org/nuclear-monitor/865/nuclear-lobbyist-michael-shellenberger-learns-love-bomb-goes-down-rabbit-hole

[280] Environmental Progress, 2018, Nations Building Nuclear – Proliferation Analysis, https://docs.google.com/spreadsheets/d/1YA4gLOekXNXiwpggCEx3uUpeu_STBlN_gHD60B5QG1E/edit#gid=0

[281] Michael Shellenberger, 29 Aug 2018, 'For Nations Seeking Nuclear Energy, The Option To Build A Weapon Remains A Feature Not A Bug', https://www.forbes.com/sites/michaelshellenberger/2018/08/29/for-nations-seeking-nuclear-energy-the-option-to-build-a-weapon-remains-a-feature-not-a-bug/

[282] Matthew Fuhrmann and Benjamin Tkach, 8 Jan 2015, 'Almost nuclear: Introducing the Nuclear Latency dataset', Conflict Management and Peace Science,
https://doi.org/10.1177/0738894214559672
http://journals.sagepub.com/doi/abs/10.1177/0738894214559672

[283] Michael Shellenberger, 29 Aug 2018, 'For Nations Seeking Nuclear Energy, The Option To Build A Weapon Remains A Feature Not A Bug', https://www.forbes.com/sites/michaelshellenberger/2018/08/29/for-nations-seeking-nuclear-energy-the-option-to-build-a-weapon-remains-a-feature-not-a-bug/

[284] https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf

[285] Helmut Hirsch, Oda Becker, Mycle Schneider and Antony Froggatt, April 2005, 'Nuclear Reactor Hazards: Ongoing Dangers of Operating Nuclear Technology in the 21st Century', report prepared for Greenpeace International, https://www.researchgate.net/publication/262630918

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 converted 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."

Nuclear transport security issues are discussed in greater detail in section 4.10 (pp.243–250) of the joint submission to the SA Nuclear Fuel Cycle Royal Commission by Friends of the Earth Australia, the Australian Conservation Foundation, and Conservation SA.[286]

9.6 Australian nuclear security issues

Security incidents at ANSTO's Lucas Heights site in southern Sydney include the following[287]:

- 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 Lucas Heights reactor by Afghan sympathisers of Osama bin Laden.
- 9 October 2001: NSW and Federal police conducted a 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 and held on suspicion of terrorism in France. He was 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

[286] https://nuclear.foe.org.au/wp-content/uploads/NFCRC-submission-FoEA-ACF-CCSA-FINAL-AUGUST-2015.pdf
[287] Tilman Ruff, 2006, 'Nuclear Terrorism', EnergyScience Coalition Briefing Paper #10, www.energyscience.org.au/FS10%20Nuclear%20Terrorism.pdf

nation's prime terrorist targets is protected by a cheap padlock and a stern warning against trespassing or blocking the driveway."[288]

- 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.[289]

Nuclear engineers Alan Parkinson and John Large have warned that Australia's proposed national radioactive waste facility would be attractive to terrorists wanting to make a 'dirty bomb', a radioactive weapon delivered by conventional means. The same risk applies to any comparable store of nuclear materials. When the Howard government was planning a repository in SA, the government envisaged that there would be no on-site security presence whatsoever. When later governments planned a repository and waste store in the NT, it was envisaged that would be a small on-site security presence (two guards at any one time). The more dangerous waste forms (long-lived intermediate-level waste, stored above ground) would be more easily accessible than less dangerous forms (low-level waste buried in a repository).

A number of problems with Australia's approach to nuclear security issues are discussed in the following article:
'Nuclear security and Australia's uranium exports', 8 April 2014, Online Opinion, http://onlineopinion.com.au/view.asp?article=16197

[288] Jonathan Porter, 19 Nov 2005, 'Nuclear site left exposed at the back door', *The Australian*.
[289] Sally Neighbour, 2 July 2007, 'Nations linked by blood and Islam', *The Australian*.
Charles Ferguson, 9 Jan 2007, 'Nuclear risk could be an inside job', www.smh.com.au/news/opinion/nuclear-risk-could-be-an-inside-job/2007/01/08/1168104921045.html

APPENDIX 1: SOUTH KOREA'S TROUBLED NUCLEAR INDUSTRY AS A POTENTIAL SUPPLIER OF REACTOR TECHNOLOGY TO AUSTRALIA

Few options would be available should Australia decide to pursue nuclear power. Westinghouse AP1000 reactors and French EPR reactors would be ruled out in light of the extraordinary delays and cost overruns with those reactors overseas, especially in the US and Europe.[290] Chinese or Russian nuclear reactors would not be accepted in Australia for a multitude of reasons including cybersecurity, corruption, repression and civil rights considerations, safety, and inadequate regulation.

Few if any options would be available other than South Korean nuclear agencies (and even they might not be willing suppliers in light of the nuclear power phase-out policy of current President Moon Jae-in). According to the Australian Nuclear Association: "Possibly the most reliable current supplier of new nuclear power plants is found in South Korea."[291]

However any South Korean supply of reactor technology to Australia would be deeply problematic for a variety of reasons: South Korea is slowly phasing out nuclear power; it has little experience with its APR1400 reactor design; it has not won a single export contract since 2009 (and that project is behind schedule and over-budget); and South Korea's 'nuclear mafia' has a track record of corruption with adverse impacts on nuclear safety.

It can safely be assumed that South Korean nuclear agencies would not contemplate building reactors in Australia in the absence of massive taxpayer subsidies. Evidence for that statement can be found in Moorside in the UK, where South Korean nuclear agencies declined the opportunity to pursue a reactor building program (after Toshiba's withdrawal from the NuGen consortium) despite the likely availability of massive taxpayer subsidies to pursue the project (as with the Hinkley Point C project which is proceeding with massive government subsidies, and the Wylfa project which was abandoned by Hitachi despite government offers of massive subsidies.)

In 2010, South Korea's Ministry of Knowledge Economy (now the Ministry of Trade, Industry, and Energy) stated that it aimed to achieve exports of 80 nuclear power reactors worth US$400 billion by 2030.[292] Yet as the *Financial Times* noted in February 2017, that objective is now viewed as "wildly ambitious" and South Korea hasn't won a single bid to build reactors since 2009, when it secured the contract to build four reactors in the United Arab Emirates.[293] South Korea has signed nuclear cooperation agreements with at least 27 countries[294] but the agreements are not leading to reactor supply contracts.[295]

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[290] https://nuclear.foe.org.au/wp-content/uploads/Nuclear-power-economic-crisis-July-2019-FoE-Aust.pdf

[291] https://nuclearforclimate.com.au/2019/03/03/chapter-3-so-what-type-and-where-would-we-build-nuclear-power-plants-in-australia/

[292] Robert Einhorn, Fred F. McGoldrick, James L. Tyson, and Duyeon Kim, 16 Jan 2015, 'ROK-U.S. Civil Nuclear and Nonproliferation Collaboration in Third Countries', https://www.brookings.edu/wp-content/uploads/2016/06/ROK-US-Civil-Nuclear-and-Nonproliferation-Collaboration-in-Third-Countries.pdf

[293] Kana Inagaki, Leo Lewis and Ed Crooks, 15 Feb 2017, 'Downfall of Toshiba, a nuclear industry titan', www.ft.com/content/416a2c9c-f2d3-11e6-8758-6876151821a6

[294] Robert Einhorn, Fred F. McGoldrick, James L. Tyson, and Duyeon Kim, 16 Jan 2015, 'ROK-U.S. Civil Nuclear and Nonproliferation Collaboration in Third Countries', https://www.brookings.edu/wp-content/uploads/2016/06/ROK-US-Civil-Nuclear-and-Nonproliferation-Collaboration-in-Third-Countries.pdf

[295] Nuclear Monitor #844, 25 May 2017, 'Is South Korea's nuclear industry a model for others to follow?', https://www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-industry-model-others-follow

There is little operating experience with APR1400 reactors. Only two are operating – Shin Kori #3 and #4, with first grid connection in January 2016 and April 2019, respectively. Two other APR1400 reactors are under construction in South Korea, and four in the UAE.

Academic Steve Thomas noted in a 2014 paper that Korean authorities acknowledge that the APR1400 would not meet US or European requirements, particularly on aircraft crash protection and, for Europe, a core-catcher.[296] (The APR1400 has since progressed through the licensing process in the US, through some combination of heightened safety standards and/or lowered expectations by the US Nuclear Regulatory Commission. In any case, no reactors will be built in the US for the foreseeable future in the aftermath of the spectacular failures with the V.C. Summer and Vogtle projects.)

Anne Lauvergeon, the CEO of Areva when the French utility lost its bid to build reactors in the UAE, was scathing about Korea's APR1400 design. *Nucleonics Week* reported:[297]
"She [Lauvergeon] mentioned in particular that EPR's containment was designed to withstand the crash of a large jet aircraft and had a provision to prevent molten corium from penetrating the reactor basemat if the core melted through the reactor vessel. She likened the Korean reactor – which she said had neither such feature – to 'a car without airbags and safety belts.'"

The safety and forgery corruption scandal (discussed below) that first emerged in 2012 has delayed the APR1400 projects in South Korea. Rod Adams wrote in *Forbes*:[298]
"That reactor [Shin Kori #3], the world's first APR1400 was initially scheduled to begin operating in 2013 and to be in commercial service by mid to late 2014. That plan was perturbed when inspectors in Korea found substandard control and safety system cabling installed in a number of Korean nuclear plants. The investigation eventually revealed that Shin Kori unit 3 had out-of-specification cables installed. The complete cycle of discovery, corrective action determination and cable replacement delayed the commercial operation of Shin Kori unit 3 by more than two years."

The delays in South Korea have also delayed completion of the APR1400 reactors in the UAE.[299]

The completion of four APR1000 reactors on-time and on-budget in the UAE is held up by nuclear lobbyists to be one of the industry's few good-news stories. But the reality is that these reactors will not be completed on schedule or on-budget. At best, the first reactor will be grid-connected in 2020, approximately three years behind schedule, 11 years after the contract was signed and eight years after construction began. The discovery of cracks in reactor containment buildings partly explains the delays.[300]

The cost of the four reactors in the UAE is widely reported to be US$20 billion and South Korea is widely believed to have pursued the project on a loss-leader basis – offering a low price in a (failed)

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[296] Steve Thomas, July 2014, 'Nuclear technology options for South Africa', http://earthlife.org.za/www/wp-content/uploads/2014/09/nuclear-cost_report1.pdf
[297] Nucleonics Week, 22 April 2010, 'No core catcher, double containment for UAE reactors, South Koreans say', https://online.platts.com/PPS/P=m&e=1272486727325.13004128321662479/NW_20100422.xml?artnum=C2010w04211EqR62MT1W03_4
[298] Rod Adams, 4 May 2017, 'Delayed Start Up At Shin Kori Unit 3 In South Korea Delays Barakah Unit 1 Start Up In UAE', www.forbes.com/sites/rodadams/2017/05/04/delayed-start-up-at-shin-kori-unit-3-in-south-korea-delays-barakah-unit-1-start-up-in-uae/#38d727e67d6a
[299] Reuters, 5 May 2017, 'Exclusive - UAE delays launch of first nuclear power reactor: source', https://uk.reuters.com/article/uk-kepco-emirates-nuclearpower-exclusive/exclusive-uae-delays-launch-of-first-nuclear-power-reactor-source-idUKKBN1801Z5
[300] 17 Oct 2018, 'KEPCO undergoes repairs for cracks in nuclear reactor containment buildings in UAE', http://english.hani.co.kr/arti/english_edition/e_business/866228.html

attempt to kick-start a nuclear export business. Areva's bid is believed to have been almost twice as high (US$36 billion).[301] The three-year delay (which could become an even longer delay) must have increased costs – but no information is publicly available on the cost escalation. As noted immediately below, there is speculation that costs have risen to US$32 billion (A$47.3 billion) including infrastructure and finance.

The 2016 World Nuclear Industry Status Report collated available information on the cost of the UAE reactor project:[302]
"At the time of the contract signing in December 2009, with Korean Electric Power Corp., the Emirates Nuclear Energy Corp (ENEC), said that "the contract for the construction, commissioning and fuel loads for four units equaled approximately US$20 billion, with a high percentage of the contract being offered under a fixed-price arrangement". The original financing plan for the project was thought to include US$10 billion from the Export Import Bank of Korea, US$2 billion from the Ex-Im Bank of the U.S., US$6 billion from the government of Abu Dhabi, and US$2 billion from commercial banks. However, it is unclear what other financing sources have been used for the project, and it is reported that the cost of the project has risen significantly, with the total cost of the plant including infrastructure and finance now expected to be about US$32 billion, with others putting the cost of the contracts at US$40 billion, including fuel management and operation, although little independent information is available."

Security is another concern. *Yonhap News* reported in May 2017 that a report by KHNP noted that South Korea's power reactors have not been designed to deal with military attacks – the outer protective walls were not designed to withstand a missile strike or other forms of concerted attacks.[303] Kim Jong-hoon, a parliamentarian representing the conservative Liberty Korea Party, said that Seoul was several years behind the US in coming up with safety measures to deal with military and terrorist attacks. "The fact that the country has not taken action in the past is a serious lapse, especially with North Korea's evolving missile threats," Kim said.[304]

Plan to build one or more 'SMART' SMRs in Saudi Arabia

South Korea may have found a model to unlock the potential of small modular reactors (SMRs): collaboration with a repressive Middle Eastern state (the Kingdom of Saudi Arabia) coupled with extensive nuclear technology transfer that could facilitate the Kingdom's weapons ambitions. There is real concern that such actions will fan proliferation risks and tensions in a volatile region.

In March 2015, the Korea Atomic Energy Research Institute (KAERI) signed a memorandum of understanding with Saudi Arabia's King Abdullah City for Atomic and Renewable Energy (KACARE) to carry out a study to assess the feasibility of building two first-of-a-kind 'System Integrated Modular Advanced ReacTor' (SMART) reactors. SMART is a 100 MWe pressurized water reactor design which could be used for electricity generation and desalinisation. The cost of building the first SMART reactor in Saudi Arabia is estimated at US$1 billion.[305]

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[301] Max S. Kim, 22 April 2019, 'How greed and corruption blew up South Korea's nuclear industry', https://www.technologyreview.com/s/613325/how-greed-and-corruption-blew-up-south-koreas-nuclear-industry/
[302] Mycle Schneider, Antony Froggatt et al., 2016, World Nuclear Industry Status Report 2016, www.worldnuclearreport.org or direct download: www.worldnuclearreport.org/IMG/pdf/20160713MSC-WNISR2016V2-HR.pdf
[303] Yonhap News, 16 April 2017, 'S. Korea's nuclear power reactors not designed to deal with military attacks', https://en.yna.co.kr/view/AEN20170416002800320
[304] Ibid.
[305] WNN, 4 March 2015, 'Saudi Arabia teams up with Korea on SMART', www.world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html

Among other obstacles, the development of SMART technology has only lukewarm support from the South Korean government; it is no longer financially backed by Korea Electric Power Co. (Kepco); there is no intention to deploy SMART reactors in South Korea; and plans to build a demonstration plant in South Korea stalled (it was "not practical or economic" according to the World Nuclear Association[306]).

KACARE says that SMART intellectual property rights will be co-owned and that, in addition to the construction of SMART reactors in Saudi Arabia, the two countries aim to commercialise the technology and to promote it worldwide.[307]

The joint partnership − and the extensive technology transfer and training it entails − will take Saudi Arabia further down the path towards developing a latent nuclear weapons capability. Saudi officials have made no secret of the Kingdom's intention to pursue a weapons program if Iran's nuclear program is not constrained.[308]

Wall Street Journal reporters noted in March 2015:[309]
"As U.S. and Iranian diplomats inched toward progress on Tehran's nuclear program last week, Saudi Arabia quietly signed its own nuclear-cooperation agreement with South Korea. That agreement, along with recent comments from Saudi officials and royals, is raising concerns on Capitol Hill and among U.S. allies that a deal with Iran, rather than stanching the spread of nuclear technologies, risks fueling it."

The project appears to have been delayed or stalled with a November 2018 report in *Business Korea* suggesting that the project may be in jeopardy.[310]

Corruption scandal and South Korea's 'nuclear mafia'

In May 2012, five engineers were charged with covering up a potentially dangerous power failure at the Kori-1 reactor which led to a rapid rise in the reactor core temperature.[311] The accident occurred because of a failure to follow safety procedures. A manager decided to conceal the incident and to delete records, despite a legal obligation to notify the Nuclear Safety and Security Commission.

Around the same time, a much bigger and broader scandal emerged involving fake safety certifications for reactor parts, sub-standard reactor parts, and bribery.[312] The corrupt practices stretched back to 2004 if not earlier.[313]

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[306] http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx
[307] KACARE, 3 March 2015, 'MOU's Signature', www.kacare.gov.sa/en/?p=1667
[308] 18 Sept 2014, 'Saudi Arabia's nuclear power program and its weapons ambitions', Nuclear Monitor, Issue #791, www.wiseinternational.org/node/4195
[309] Jay Solomon and Ahmed Al Omran, 11 March 2015, 'Saudi Nuclear Deal Raises Stakes for Iran Talks', www.wsj.com/articles/saudi-nuclear-deal-raises-stakes-for-iran-talks-1426117583
[310] Jung Suk-yee, 16 Nov 2018, 'Small Modular Reactor Export from S. Korea in Jeopardy', http://www.businesskorea.co.kr/news/articleView.html?idxno=26628
[311] Nuclear Monitor #765, 1 Aug 2013, 'South Korea: Nuclear scandal widens', www.wiseinternational.org/nuclear-monitor/765/nuclear-news
[312] Nuclear Monitor #844, 25 May 2017, 'South Korea's 'nuclear mafia'', www.wiseinternational.org/nuclear-monitor/844/south-koreas-nuclear-mafia
See also: Nuclear Monitor #771, 2 Nov 2013, 'South Korea indicts 100 people over safety scandals', www.wiseinternational.org/nuclear-monitor/771/south-korea-indicts-100-people-over-safety-scandals
See also: Nuclear Monitor #765, 1 Aug 2013, 'South Korea: Nuclear scandal widens', www.wiseinternational.org/nuclear-monitor/765/nuclear-news
[313] Will Davis, 6 Feb 2014, 'South Korea nuclear power: Are the dark times over?', http://ansnuclearcafe.org/2014/02/06/south-korea-nuclear-power-are-the-dark-times-over/

Here is a summary of the scandal from the World Nuclear Association:[314]
"In 2012 KHNP [Korea Hydro & Nuclear Power] discovered that it had been supplied with falsely-certified non-safety-critical parts for at least five power reactors. The utility told the ministry that eight unnamed suppliers – reportedly seven domestic companies and one US company – forged some 60 quality control certificates covering 7682 components delivered between 2003 and 2012. The majority of the parts were installed at Hanbit (Yonggwang) units 5 and 6, while the rest were used at Hanbit units 3 and 4 and Hanul (Ulchin) unit 3. Hanbit units were taken offline while the parts were replaced.
"Then in May 2013 safety-related control cabling with falsified documentation was found to have been installed at four reactors. The NSSC [Nuclear Safety and Security Commission] ordered KHNP immediately to stop operation of its Shin Kori 2 and Shin Wolsong 1 units and to keep Shin Kori 1, which has been offline for scheduled maintenance, shut down. In addition, the newly-constructed Shin Wolsong 2, which was awaiting approval to start commercial operation, could not start up. All would remain closed until the cabling has been replaced, which was expected to take about four months. Shin Kori 1&2 and Shin Wolsong 1 were cleared to restart in January 2014. Completion of Shin Kori 3&4 was delayed, to 2015, due to the need to replace control cabling which failed tests. In October 2013 about 100 people were indicted for their part in the falsification of documentation."

The Korea Institute of Nuclear Safety states:[315]

- A total of 2,114 test reports were falsified: 247 test reports in relation to replaced parts for 23 reactors, an additional 944 falsifications in relation to 'items' for three recently commissioned reactors, and 923 falsifications in relation to 'items' for five reactors under construction.
- Results were 'unidentified' for an additional 3,408 test reports – presumably it was impossible to assess whether or not the reports were falsified.
- Twenty-nine of the forgeries concerned 'seismic qualification', with the legitimacy of a further 43 seismic reports 'unclear'.
- Over 7,500 reactor parts were replaced in the aftermath of the scandal.

Safety-related equipment was installed on the basis of falsified documentation, and according to a whistleblower, equipment had actually failed under Loss-Of-Coolant-Accident conditions during at least one concealed test.[316]

The situation in Korea is similar to that in Japan prior to the Fukushima disaster and involves systemic corruption. The primary difference between the two sectors is that Japan's corrupt nuclear establishment is known as the 'nuclear village'[317] whereas South Korea's corrupt nuclear establishment is known as the 'nuclear mafia'.[318]

A 2014 parliamentary audit revealed that the temporary suspension of the operations of nuclear power plants after the scandal caused the loss of 10 trillion won (A$12.3 billion).[319] It also led to power shortages.

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[314] World Nuclear Association, Feb 2017, 'Nuclear Power in South Korea', www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx
[315] Korea Institute of Nuclear Safety, www.kins.re.kr/en/ourwork/cfsi.jsp
[316] Mycle Schneider, Antony Froggatt et al., 2016, World Nuclear Industry Status Report 2016, www.worldnuclearreport.org or direct download: www.worldnuclearreport.org/IMG/pdf/20160713MSC-WNISR2016V2-HR.pdf
[317] Friends of the Earth, March 2012, 'Japan's Nuclear Scandals and the Fukushima Disaster', http://archive.foe.org.au/sites/default/files/FUKUSHIMA_BRIEFING_MARCH_2012_0.pdf
[318] Korea Times, 25 June 2016, 'Fake certificates again', http://koreatimes.co.kr/www/news/opinon/2014/06/137_159789.html
[319] Se Young Jang, 8 Oct 2015, 'The Repercussions of South Korea's Pro-Nuclear Energy Policy', http://thediplomat.com/2015/10/the-repercussions-of-south-koreas-pro-nuclear-energy-policy/

Nuclear power advocate Will Davis wrote this summary of the scandals in 2014:[320]
"Electing for brevity, suffice it to say that various schemes to advance the position of persons or companies in the South Korean nuclear industry have resulted in substandard parts being employed (particularly cable supplied by JS Cable, a company that is presently being liquidated), false quality assurance certificates being filed, and various collusion/bribery schemes among varied personnel at contractors and in the KHNP universe of subsidiaries – with involvement reaching even to the highest (former) executives.
"While the true extent and nature of these corrupt activities began to be illuminated only at the end of 2011, in fact the activities stretched far prior; a recent article in the Korea Herald noted that JS Cable failed to obtain certification for nuclear parts for its product twice in 2004, and then somehow immediately made a sale of such equipment for a total of 5.5 billion won (US$5.06 million). That cabling was eventually found to be defective when it triggered shutdowns at two nuclear plants, in May 2013. Many corporate offices (including those of KHNP) were raided throughout the summer, and many arrests made – arrests that included a former president of KHNP.
"Much more than cable from one company has been implicated; implicated parts (questionable parts, or questionable certifications, or both) were thought to possibly be in service at as many as 11 nuclear plants in South Korea. A massive program to find all such parts and associated companies and persons was launched and pressed with a vigor and aggression not normally seen in industrially related investigations."

Corruption also affected South Korea's reactor construction project in the UAE. Hyundai Heavy Industries employees offered bribes to KHNP officials in charge of the supply of parts for reactors to be exported to the UAE.[321]

The *New York Times* reported in August 2013 that despite the government's pledge to ban parts suppliers found to have falsified documents from bidding again for 10 years, KHNP imposed only a six-month penalty for such suppliers.[322] The *New York Times* continued:
"And nuclear opponents say that more fundamental changes are needed in the regulatory system, pointing out that one of the government's main regulating arms, the Korea Institute of Nuclear Safety, gets 60 percent of its annual budget from Korea Hydro."

Worse still, a 2014 parliamentary audit revealed that some officials fired from KEPCO E&C (Korea Electric Power Corporation Engineering and Construction) over the scandals were later rehired.[323]

The scandal was still on the boil in 2014. *Korea Times* reported on 25 June 2014:[324]
"The government has discovered irregularities yet again that could threaten the safety of nuclear reactors. This time, the perpetrators are parts suppliers that presented fake quality certificates in the course of replacing antiquated parts used in nuclear power plants. Six state testing facilities were also found to have failed to conduct adequate tests before issuing certificates. A two-month audit of the six

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[320] Will Davis, 6 Feb 2014, 'South Korea nuclear power: Are the dark times over?', http://ansnuclearcafe.org/2014/02/06/south-korea-nuclear-power-are-the-dark-times-over/
[321] Choi Kyong-ae, 12 Jan 2014, 'Hyundai Heavy vows to root out corruption', http://koreatimes.co.kr/www/news/biz/2014/01/602_149613.html
[322] Choe Sang-hun, 3 Aug 2013, 'Scandal in South Korea Over Nuclear Revelations', www.nytimes.com/2013/08/04/world/asia/scandal-in-south-korea-over-nuclear-revelations.html
[323] Se Young Jang, 8 Oct 2015, 'The Repercussions of South Korea's Pro-Nuclear Energy Policy', http://thediplomat.com/2015/10/the-repercussions-of-south-koreas-pro-nuclear-energy-policy/
[324] Korea Times, 25 June 2016, 'Fake certificates again', http://koreatimes.co.kr/www/news/opinon/2014/06/137_159789.html

testing facilities by the Ministry of Trade, Industry and Energy showed that 39 quality certificates presented by 24 companies were fabricated. ...
"Most disheartening in the latest revelation of irregularities is that the state-run certifiers failed to detect fabrications by skipping the required double-testing. ... Given the magnitude of corruption in the nuclear industry arising from its intrinsic nature of being closed, the first step toward safety should be to break the deep-seated food chain created by the so-called nuclear mafia, which will help enhance transparency ultimately. With the prosecution set to investigate the suppliers, the certifiers will face business suspension. But it's imperative to toughen penalties for them, considering that light punitive measures have stood behind the lingering corruption in the nuclear industry."

Opposition to South Korea's corrupt 'nuclear mafia' feeds into broader concerns about corruption. *Japan Times* reported in May 2017:[325]
"Opinion polls taken just before the election showed that the top concern for the country's voters was "deep-rooted corruption" and a desire to promote reform; second on that list was economic revival. If Moon is to succeed in those tasks, he must tackle the chaebol, the huge industrial conglomerates that dominate the South Korean economy and have outsized influence in its politics."

Japan's corrupt 'nuclear village' survived the political fallout from the Fukushima disaster and is back in charge.[326] It would be naïve to imagine that the tepid response to South Korea's scandals has done away with the 'nuclear mafia' once and for all. There were another six arrests related to nuclear corruption in 2018, an outcome that only scratched the surface of the corruption according to a whistleblower.[327]

An April 2019 article in *MIT Technology Review* provides further detail and an update on the corruption scandals:[328]
"On September 21, 2012, officials at KHNP had received an outside tip about illegal activity among the company's parts suppliers. By the time President Park had taken office, an internal probe had become a full-blown criminal investigation. Prosecutors discovered that thousands of counterfeit parts had made their way into nuclear reactors across the country, backed up with forged safety documents. KHNP insisted the reactors were still safe, but the question remained: was corner-cutting the real reason they were so cheap?
"Park Jong-woon, a former manager who worked on reactors at Kepco and KHNP until the early 2000s, believed so. He had seen that taking shortcuts was precisely how South Korea's headline reactor, the APR1400, had been built.
"After the Chernobyl disaster in 1986, most reactor builders had tacked on a slew of new safety features. KHNP followed suit but later realized that the astronomical cost of these features would make the APR1400 much too expensive to attract foreign clients. They eventually removed most of them," says Park, who now teaches nuclear engineering at Dongguk University. "Only about 10% to 20% of the original safety additions were kept."
"Most significant was the decision to abandon adding an extra wall in the reactor containment building – a feature designed to increase protection against radiation in the event of an accident. "They packaged the APR1400 as 'new' and safer, but the so-called optimization was essentially a regression to

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[325] Japan Times, 10 May 2017, 'The pendulum swings in South Korea', www.japantimes.co.jp/opinion/2017/05/10/editorials/pendulum-swings-south-korea/
[326] Nuclear Monitor #800, 19 March 2015, 'Japan's 'nuclear village' reasserting control', www.wiseinternational.org/nuclear-monitor/800/japans-nuclear-village-reasserting-control
[327] Max S. Kim, 22 April 2019, 'How greed and corruption blew up South Korea's nuclear industry', https://www.technologyreview.com/s/613325/how-greed-and-corruption-blew-up-south-koreas-nuclear-industry/
[328] Ibid.

older standards," says Park. "Because there were so few design changes compared to previous models, [KHNP] was able to build so many of them so quickly."
"Having shed most of the costly additional safety features, Kepco was able to dramatically undercut its competition in the UAE bid, a strategy that hadn't gone unnoticed. After losing Barakah to Kepco, Areva CEO Anne Lauvergeon likened the Korean unit to a car without airbags and seat belts. When I told Park this, he snorted in agreement. "Objectively speaking, if it's twice as expensive, it's going to be about twice as safe," he said. At the time, however, Lauvergeon's comments were dismissed as sour words from a struggling rival.
"By the time it was completed in 2014, the KHNP inquiry had escalated into a far-reaching investigation of graft, collusion, and warranty forgery; in total, 68 people were sentenced and the courts dispensed a cumulative 253 years of jail time. Guilty parties included KHNP president Kim Jong-shin, a Kepco lifer, and President Lee Myung-bak's close aide Park Young-joon, whom Kim had bribed in exchange for "favorable treatment" from the government.
"Several faulty parts had also found their way into the UAE plants, angering Emirati officials. "It's still creating a problem to this day," Neilson-Sewell, the Canadian advisor to Barakah, told me. "They lost complete faith in the Korean supply chain."
"The scandals, however, were not over. Earlier this year, at a small bakery in Seoul, I met Kim Min-kyu. A slight 44-year-old man with earnest, youthful eyes, Kim used to be a senior sales manager at Hyosung Heavy Industries, a manufacturer of reactor parts. In 2010, he was put in charge of selling to KHNP and quickly discovered that double-dealing was as routine as paperwork.
""Suppliers who were supposed to be competing with one another colluded to decide who would win [KHNP bids]," Kim told me. "You'd have a group of white-haired executives from competing firms sitting across from each other, playing rock-paper-scissors to decide who would take certain contracts." Dummy bids would then be supported by fake documents, doctored to ensure that the designated loser would fail. On one occasion, he says, an irate KHNP procurement manager called him to point out an amateurish forgery in a fake bidding document – and demanded he do it again, properly.
"Some of these practices constituted serious lapses in safety. In May 2014, Kim oversaw the delivery of 11 load center transformers bound for the Hanul Nuclear Power Plant in North Gyeongsang province, only to discover that their safety licenses hadn't been renewed. Load center transformers manage the flow of power to key emergency functions at reactors; any malfunction, Kim told me, would be "like a hurtling car suddenly stalling."
"Yet a secret agreement between Hyosung and competitors had designated it the winner, and the transformers were installed into two reactors, their integrity unquestioned. "I personally knew of around 300 cases where those transformers caught on fire. They're incredibly unstable," says Kim, his brow furrowed. "My hometown is actually just a few kilometers from those reactors, and an accident there could endanger my relatives who live nearby."
"In 2015, fearing a Fukushima-like accident, Kim decided to report the corruption through his company's internal whistleblowing system. The only result was that he was fired.
""How naïve I was," he says, flashing a rueful grin. He eventually went to the country's competition regulator, which referred the case to prosecutors. In 2018, he took his story to the media. A few months later, on the basis of tips from Kim, prosecutors charged six employees from Hyosung and co-conspirator LS Industrial Systems with collusion – an outcome that Kim believes only scratches the surface of the corruption.
"More untruths soon came to light. In 2018, after years of government denial, former defense minister Kim Taeyoung admitted that the rumors about the military side agreement with the UAE were, in fact, true: he had overseen it himself in a desperate attempt to seal the Barakah deal. "There was low risk of a dangerous situation arising, and even if it did, we believed that our response could be flexible," he told South Korean media. "In the event of an actual conflict, I figured that we would ask for parliamentary ratification then." ...

"On principle, I don't trust anything that KHNP built," says Kim Min-kyu, the corruption whistleblower. More and more South Koreans have developed a general mistrust of what they refer to as "the nuclear mafia" – the close-knit pro-nuclear complex spanning KHNP, academia, government, and monied interests. Meanwhile the government watchdog, the Nuclear Safety and Security Commission, has been accused of revolving door appointments, back-scratching, and a disregard for the safety regulations it is meant to enforce."

The secret military side-agreement to the South Korea / UAE nuclear contract has led to debate as to whether the Lee government violated the constitution when it signed the agreement without the approval of the National Assembly.[329] A confidential US briefing leaked by Wikileaks said the military side-agreement covered defense industry technology exchanges, cooperation on military training and support, and exchanges of high-ranking military officials.[330] Kim Tae-young, who served as Defense Minister under the Lee administration from September 2009 to December 2010, said: "At the time, France had nearly clinched the UAE nuclear reactor deal. South Korea needed to show it was fully committed to the UAE. We signed an agreement for the South Korean military to intervene if the UAE runs into military trouble."[331]

Inadequate safety standards still in evidence in 2019

Inadequate nuclear safety standards are still in evidence in 2019. A case in point is an incident at the Hanbit 1 reactor on 10 May 2019. The reactor's thermal output exceeded safety limits but was kept running for nearly 12 hours when it should have been shut down manually at once.[332] The thermal output rose from 0% to 18% in one minute, far exceeding the 5% threshold that should have triggered a manual shutdown.

The Nuclear Safety and Security Commission (NSSC) ordered the suspension of operation of the nuclear power plant and dispatched a team of special judiciary police officers to carry out a special inspection.[333] The NSSC said in a May 20 statement:[334]
"The NSSC confirmed that the KHNP did not immediately stop the reactor even though the thermal output of the reactor exceeded the limit during the Control Element Reactivity Measurement Test and that the control rod was operated by a person who does not have a Reactor Operator's license (RO). The NSSC said that negligence of the person having a Senior Reactor Operator's license (SRO) in supervising and directing the operation is suspected, and therefore there is a possibility of violating the Nuclear Safety Act."

[329] Lee Seung-jun, 10 Jan 2018, 'Secret military pact likely led to Blue House Chief of Staff's UAE visit', http://english.hani.co.kr/arti/english_edition/e_international/827153.html
[330] 4 Jan 2010, 'ROK FM YU ON ROK'S COMPREHENSIVE DEAL WITH UAE', https://wikileaks.org/plusd/cables/10SEOUL2_a.html
[331] Lee Seung-jun, 10 Jan 2018, 'Secret military pact likely led to Blue House Chief of Staff's UAE visit', http://english.hani.co.kr/arti/english_edition/e_international/827153.html
[332] Choi Ha-yan, 21 May 2019, 'Nuclear reactor kept running for 12 hours after it should have been shut down', http://english.hani.co.kr/arti/english_edition/e_business/894763.html
[333] Nuclear Safety and Security Commission, 20 May 2019, 'The NSSC to Expand the Special Inspection on Manual Shutdown of Hanbit Unit 1', http://www.nssc.go.kr/nssc/en/c5/sub1.jsp?mode=view&article_no=45431&pager.offset=30&board_no=501
[334] Nuclear Safety and Security Commission, 20 May 2019, 'The NSSC to Expand the Special Inspection on Manual Shutdown of Hanbit Unit 1', http://www.nssc.go.kr/nssc/en/c5/sub1.jsp?mode=view&article_no=45431&pager.offset=30&board_no=501

The NSSC said on June 25:[335]
"According to the midterm results of the special investigation on the Hanbit Unit 1, which was released on June 24th, the event happened because the licensee (the Korea Hydro and Nuclear Power) did not abide by the Nuclear Safety Act, Technical Specifications and internal procedures".

The Hanbit-1 incident was one of three occasions in 2019 when a reactor was shut down soon after being reactivated. The *Hankyoreh* newspaper editorialised on 9 September 2019:[336]
"South Korean nuclear power plants that have reopened following government approval have faced a string of malfunctions, bringing their operations to a halt. These accidents raise worrying questions about the safety of nuclear energy. There's an urgent need for nuclear energy regulators to carry out thorough inspections and to prevent such accidents from reoccurring. ... Another question that must be asked is whether regulators have been too hasty in authorizing the reactors' reactivation."

[335] Nuclear Safety and Security Commission, 25 June 2019, 'Comments on the news article: Event at Hanbit Unit 1 was caused by a violation of the law and human error and irrelevant to the energy transition policy', http://www.nssc.go.kr/nssc/en/c5/sub1.jsp?mode=view&article_no=45520&pager.offset=20&board_no=501
[336] Editorial – Hankyoreh, 9 Sept 2019, 'Nuclear energy regulators need to be more vigilant in inspections than ever', http://english.hani.co.kr/arti/english_edition/e_editorial/909073.html

APPENDIX 2: FAST NEUTRON REACTORS (A.K.A. FAST SPECTRUM OR FAST BREEDER REACTORS)

Fast reactors are "poised to become mainstream" according to the World Nuclear Association (WNA).[337] But data provided by the WNA itself suggests otherwise. The WNA lists just five operating fast reactors, all of them described by the Association as experimental or demonstration reactors (the BN-600 and BN-800 reactors generate significant amounts of electricity but are nonetheless classified as experimental or demonstration reactors, presumably because they were supposed to be forerunners to a larger (but postponed) BN-1200 reactor):

- BOR-60 experimental reactor, Russia
- BN-600 demonstration reactor, Russia
- BN-800 experimental reactor, Russia
- FBTR experimental reactor, India
- CEFR experimental reactor, China.

Of course there's always tomorrow: the WNA lists 16 fast reactor projects under "active development" for "near- to mid-term deployment".[338] But a large majority of those projects – perhaps all of them – lack both approval and funding and it is inaccurate to claim that they are under "active development" or that they are set for "near- to mid-term deployment". Very few if any will progress to construction and operation.

The historical pattern (based on WNA tables[339]) strongly suggests that fast reactors are on the way out, not on a pathway to becoming "mainstream":
1976 – 7 operable fast reactors
1986 – 11
1996 – 7
2006 – 6
2019 – 5

One country after another has abandoned fast reactor technology. Nuclear physicist Thomas Cochran summarises the history:[340]
"Fast reactor development programs failed in the: 1) United States; 2) France; 3) United Kingdom; 4) Germany; 5) Japan; 6) Italy; 7) Soviet Union/Russia 8) U.S. Navy and 9) the Soviet Navy. The program in India is showing no signs of success and the program in China is only at a very early stage of development."

It is perhaps harsh to describe Russia's fast reactor program as a failure but it is certainly modest (three experimental / demonstration reactors), and in August 2019 the program was postponed.[341]

A 2010 article in the *Bulletin of the Atomic Scientists* summarised the worldwide failure of fast reactor technology:[31]

[337] World Nuclear Association, Sept 2016, 'Fast Neutron Reactors', https://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx
[338] Ibid.
[339] Ibid.
[340] International Panel on Fissile Materials, 17 Feb 2010, 'History and status of fast breeder reactor programs worldwide', http://fissilematerials.org/library/rr08.pdf
[341] World Nuclear Association, 13 Aug 2019, 'Rosatom postpones fast reactor project, report says', http://www.world-nuclear-news.org/Articles/Rosatom-postpones-fast-reactor-project-report-say

"After six decades and the expenditure of the equivalent of about $100 billion, the promise of breeder reactors remains largely unfulfilled. ... The breeder reactor dream is not dead, but it has receded far into the future. In the 1970s, breeder advocates were predicting that the world would have thousands of breeder reactors operating this decade. Today, they are predicting commercialization by approximately 2050. In the meantime, the world has to deal with the hundreds of tons of separated weapons-usable plutonium that are the legacy of the breeder dream and more being separated each year by Britain, France, India, Japan, and Russia.
"In 1956, U.S. Navy Admiral Hyman Rickover summarized his experience with a sodium cooled reactor that powered early U.S. nuclear submarines by saying that such reactors are "expensive to build, complex to operate, susceptible to prolonged shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair." More than 50 years later, this summary remains apt."

Important recent developments: Russia and France shelve fast reactor projects

Importantly, fast reactor projects in Russia and France have been collapsing in recent months. World Nuclear Association reported in August 2019 that Russian Rosatom subsidiary "Rosenergoatom is expected to receive about USD4 billion less in state funding for the construction of new nuclear reactors in Russia owing to the postponement of its fast neutron reactor programme".[342]

The World Nuclear Association noted in June 2019 that the development of a commercial fast reactor is no longer a high priority in France and that a planned 600 MW demonstration fast reactor (ASTRID) might be scaled back to 100–200 MW.[343] Indeed the ASTRID project is in the process of being cancelled (or deferred to the second half of the century), *Le Monde* reported in August 2019: pre-project design studies will be completed then shelved; the 25-person unit coordinating the project has been disbanded; the project might be pursued in the second half of the 21st century according to CEA (while a CEA insider told *Le Monde* that the project is "mort" (dead); ASTRID has been removed from budget allocations; and the project lacks support from energy utility EDF.[344] French nuclear agency CEA confirmed the accuracy of media reports, stating: "In the current energy market situation, the perspective of industrial development of fourth-generation reactors is not planned before the second half of this century."[345] A$1.06 billion (€652 million) was allocated to the ASTRID project to 2017 and an additional A$570 million (€350 million) was allocated to 2020.[346]

One of the reasons the ASTRID project has been cancelled (or deferred to the second half of the century) is belt-tightening in the wake of another failing project: the 100 MW Jules Horowitz materials testing reactor (JHR). The cost of JHR has increased five-fold from €500 million to €2.5 billion[347] and will increase further before completion. Completion of JHR will be at least eight years behind schedule if

[342] Ibid.
[343] World Nuclear Association, June 2019, 'Nuclear Power in France', https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx
[344] Nabil Wakim, 29 Aug 2019, 'Nuclear: France abandons the fourth generation of reactors', https://www.lemonde.fr/economie/article/2019/08/29/nucleaire-la-france-abandonne-la-quatrieme-generation-de-reacteurs_5504233_3234.html
[345] Reuters, 30 Aug 2019, 'France drops plans to build sodium-cooled nuclear reactor', https://www.reuters.com/article/us-france-nuclearpower-astrid/france-drops-plans-to-build-sodium-cooled-nuclear-reactor-idUSKCN1VK0MC
[346] World Nuclear Association, June 2019, 'Nuclear Power in France', https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx
Reuters, 29 Nov 2018, 'France reviews fast-breeder nuclear reactor project', https://www.reuters.com/article/us-france-nuclearpower-astrid/france-reviews-fast-breeder-nuclear-reactor-project-idUSKCN1NY27A
[347] Ibid.

the current completion date of 2022 is met (the planned five-year construction schedule has been pushed out to 13 years).[348]

By shelving ASTRID, the French nuclear industry has avoided a repeat of its humiliating experiences with the Phénix and Superphénix fast reactors.[349] The performance of the Superphénix reactor was as dismal as Japan's Monju fast reactor. Superphénix was meant to be the world's first commercial fast reactor but in the 13 years of its existence it rarely operated – its 'Energy Unavailability Factor' was 90.8% according to the IAEA.[350]

Japan wastes tens of billions of dollars on fast reactors and reprocessing

Japan has abandoned plans to restart the Monju fast breeder reactor.[351] Monju reached criticality in 1994 but was shut down in December 1995 after a sodium coolant leak and fire. The reactor didn't restart until May 2010, and it was shut down again three months later after a fuel handling machine was accidentally dropped in the reactor during a refuelling outage. In November 2012, it was revealed that Japan Atomic Energy Agency had failed to conduct regular inspections of almost 10,000 out of a total 39,000 pieces of equipment at Monju, including safety-critical equipment.[352]

In November 2015, the Nuclear Regulation Authority declared that the Japan Atomic Energy Agency was "not qualified as an entity to safely operate" Monju. Education minister Hirokazu Matsuno said in September 2016 that attempts to find an alternative operator had been unsuccessful.[353]

The government spent ¥1.2 trillion (A$16.8 billion) on Monju and calculated that it would cost another ¥600 billion (A$8.4 billion) to restart Monju and keep it operating for another 10 years.[354] Decommissioning also has a hefty price-tag – far more than for conventional light-water reactors. According to a 2012 estimate by the Japan Atomic Energy Agency, decommissioning Monju will cost an estimated ¥300 billion (A$4.2 billion).[355]

So Japan will have wasted over A$20 billion on the Monju fiasco. The 'advanced' reactor won't be missed. The *Japan Times* reported: "Monju not only absorbed fistfuls of taxpayer money, but also

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[348] 'Jules Horowitz Reactor: a high performance material testing reactor', April–May 2008, Comptes Rendus Physique, Volume 9, Issues 3–4, https://doi.org/10.1016/j.crhy.2007.11.003
JHR: Jules Horowitz Reactor, http://roadmap2018.esfri.eu/projects-and-landmarks/browse-the-catalogue/jhr/, accessed 31 August 2019

[349] Reuters, 29 Nov 2018, 'France reviews fast-breeder nuclear reactor project', https://www.reuters.com/article/us-france-nuclearpower-astrid/france-reviews-fast-breeder-nuclear-reactor-project-idUSKCN1NY27A
Kazunari Hanawa and Shiori Goso, 19 Dec 2018, 'Japan's nuclear recycling policy runs aground', https://asia.nikkei.com/Economy/Japan-s-nuclear-recycling-policy-runs-aground

[350] www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=178
See also the following paper, which states that the lifetime load factor of Superphenix − the ratio of electricity generated compared to the amount that would have been generated if operated continually at full capacity − was a paltry 7%: http://www.princeton.edu/sgs/publications/sgs/archive/17-1-Schneider-FBR-France.pdf

[351] Reiji Yoshida, 21 Sept 2016, 'Japan to scrap troubled ¥1 trillion Monju fast-breeder reactor', www.japantimes.co.jp/news/2016/09/21/national/japans-cabinet-hold-meeting-decide-fate-monju-reactor/
Jack Loughran, 21 Sept 2016, 'Costly Japanese prototype nuclear reactor shuts down', http://eandt.theiet.org/content/articles/2016/09/costly-japanese-prototype-nuclear-reactor-shuts-down/

[352] http://www.world-nuclear-news.org/RS-New-operator-sought-for-Japans-Monju-reactor-0106165.html

[353] Reiji Yoshida, 21 Sept 2016, 'Japan to scrap troubled ¥1 trillion Monju fast-breeder reactor', www.japantimes.co.jp/news/2016/09/21/national/japans-cabinet-hold-meeting-decide-fate-monju-reactor/

[354] Mainichi Japan, 29 Aug 2016, 'Running Monju reactor for 10 years would cost gov't 600 billion yen extra', http://mainichi.jp/english/articles/20160829/p2a/00m/0na/017000c

[355] Mainichi Japan, 16 Feb 2016, 'Decommissioning of troubled fast-breeder reactor Monju would cost 300 billion yen', http://mainichi.jp/english/articles/20160216/p2a/00m/0na/005000c

suffered repeated accidents and mismanagement while only going live for a few months during its three-decade existence."[356]

Allison MacFarlane, former chair of the US Nuclear Regulatory Commission, made this sarcastic assessment of fast reactor technology: "These turn out to be very expensive technologies to build. Many countries have tried over and over. What is truly impressive is that these many governments continue to fund a demonstrably failed technology."[357]

Japan neatly illustrates MacFarlane's bemusement. Despite the Monju fiasco, the Japanese government wants to stay involved in fast reactor technology, either by restarting the Joyo experimental fast reactor (shut down since 2007 due to damage to reactor core components), or pursuing joint research with France (which seems increasingly unlikely since French interest in building a fast reactor is fading – discussed above), or building a new fast reactor in Japan.

Despite the stubborn persistence with fast reactor plans in Japan, there is every likelihood that none of the three options listed above will be pursued. Plans for a new fast reactor in Japan could hardly be vaguer, with the Ministry of Economy, Trade and Industry saying it might aim to complete and begin operating a fast reactor in the middle of this century with full operation in the second half of the century.[358]

Why would Japan continue its involvement in fast reactors? Most likely, the government has no interest in fast reactors *per se*, but giving up would make it more difficult to justify continuing with the partially-built Rokkasho reprocessing plant.[359] Providing plutonium fuel for fast reactors was one of the main justifications for Rokkasho (and the second justification, producing mixed uranium-plutonium 'MOX' fuel, also looks very shaky in the aftermath of the Fukushima disaster with as many as 26 of Japan's pre-Fukushima fleet of 54 reactors permanently shut down).

Rokkasho has been an even more expensive white elephant than Monju. Its scheduled completion in 1997 has been delayed by more than 20 times due to technical glitches and other problems, and its construction cost is now estimated at 2.2 trillion yen (A$30.80 billion) – three times the original estimate.[360]

According to the International Panel on Fissile Materials, if Rokkasho operates it is expected to increase the electricity bills of Japan's ratepayers by about US$100 billion over the next 40 years.[361]

Japan has wasted around over A$50 billion (combined) on Monju and Rokkasho for a reactor that rarely operated and a reprocessing plant that has not yet been completed and will serve no useful purpose.

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356 Reiji Yoshida, 21 Sept 2016, 'Japan to scrap troubled ¥1 trillion Monju fast-breeder reactor', www.japantimes.co.jp/news/2016/09/21/national/japans-cabinet-hold-meeting-decide-fate-monju-reactor/

357 Stephen Stapczynski and Emi Urabe, 1 June 2016, 'Japan's Nuclear Holy Grail Slips Away With Operator Elusive', http://www.bloomberg.com/news/articles/2016-05-31/nuclear-holy-grail-slips-away-from-japan-with-operator-elusive

358 Asahi Shimbun, 4 Dec 2018, 'Ministry sees Monju successor reactor running by mid-century', http://www.asahi.com/ajw/articles/AJ201812040047.html
Nuke Info Tokyo No. 188, January/February 2019, ''Strategic Road Map' for Fast Reactor Development', http://www.cnic.jp/english/?p=4290

359 http://fissilematerials.org/library/rr14.pdf

360 http://www.japantimes.co.jp/opinion/2016/09/04/editorials/monju-nuclear-fuel-cycle/

361 http://fissilematerials.org/library/rr14.pdf

Perhaps sense will prevail and Japan will abandon both fast reactors and reprocessing. Masafumi Takubo and Frank von Hippel noted in a 2016 article:[362]

"According to a 2011 estimate by Japan's Atomic Energy Commission, operating the RRP [Rokkasho Reprocessing Plant] will cost about ¥200 billion (~US$2 billion) per year to produce plutonium with a fuel value that is less than the cost of fabricating it into fuel. The economics of reprocessing in France are similarly irrational. One therefore needs to find other explanations than those stated for the persistence of reprocessing in France and Japan. Partial explanations include:

- *The thousands of jobs and government subsidies to local and regional governments associated with reprocessing and related facilities have become important to the rural areas where they are located;*
- *Abandoning the pursuit of a plutonium economy would be seen by elite nuclear technocrats as an admission that they had wasted the equivalents of tens of billions of taxpayers' dollars;*
- *Reprocessing is government policy and therefore not responsive to market economics; and*
- *In Japan, some see its reprocessing capability as providing a virtual nuclear deterrent."*

India's failed fast reactor program

India's fast reactor program has been a failure. The budget for the Fast Breeder Test Reactor (FBTR) was approved in 1971 but the reactor was delayed repeatedly, attaining first criticality in 1985. It took until 1997 for the FBTR to start supplying a small amount of electricity to the grid. The FBTR's operations have been marred by several accidents.[363]

Preliminary design work for a larger Prototype Fast Breeder Reactor (PFBR) began in 1985, expenditures on the reactor began in 1987/88 and construction began in 2004 – but the reactor still hasn't started up. Construction has taken well over twice the expected period.[364] As of 2016, the PFBR's cost estimate had gone up by 62%.[365] The PFBR has a blanket with thorium and uranium to breed fissile U-233 and plutonium respectively[366] – in other words, it will be ideal for weapons production, and it will not be subject to IAEA safeguards inspections.

India's Department of Atomic Energy (DAE) has for decades projected the construction of hundreds of fast reactors – for example a 2004 DAE document projected 262.5 gigawatts (GW) of fast reactor capacity by 2050. But India has a track record of making absurd projections for both fast reactors and light-water reactors – and failing to meet those targets by orders of magnitude.[367]

Academic M.V. Ramana wrote in 2016:[368]

"Breeder reactors have always underpinned the DAE's claims about generating large quantities of electricity. Today, more than six decades after the grand plans for growth were first announced, that promise is yet to be fulfilled. The latest announcement about the delay in the PFBR is yet another

[362] Masafumi Takubo and Frank von Hippel, 1 Sept. 2016, 'Future of Japan's Monju plutonium breeder reactor under review', http://fissilematerials.org/blog/2016/09/future_of_japans_monju_pl.html

[363] M.V. Ramana, 16 Aug 2016, 'Fast breeder reactors and the slow progress of India's nuclear programme', www.ideasforindia.in/article.aspx?article_id=1677

[364] Ibid.

[365] Mycle Schneider, Antony Froggatt et al., 2016, World Nuclear Industry Status Report 2016, www.worldnuclearreport.org/IMG/pdf/20160713MSC-WNISR2016V2-HR.pdf

[366] https://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx

[367] M.V. Ramana, 16 Aug 2016, 'Fast breeder reactors and the slow progress of India's nuclear programme', www.ideasforindia.in/article.aspx?article_id=1677

[368] Ibid.

reminder that breeder reactors in India, like elsewhere, are best regarded as a failed technology and that it is time to give up on them."

Russia has postponed its snail-paced fast reactor program

Three fast reactors are in operation in Russia – BOR-60 (start-up in 1969), BN-600 (1980) and BN-800 (2014).[369] There have been 27 sodium leaks in the BN-600 reactor, five of them in systems with radioactive sodium, and 14 leaks were accompanied by burning of sodium.[370]

The Russian government published a decree in August 2016 outlining plans to build 11 new reactors over the next 14 years.[371] Of the 11 proposed new reactors, three were fast reactors: BREST-300 near Tomsk in Siberia, and two BN-1200 fast reactors near Ekaterinburg and Chelyabinsk, near the Ural mountains.[372] However, like India, the Russian government has a track record of projecting rapid and substantial nuclear power expansion – and failing miserably to meet the targets.

As noted above, the World Nuclear Association reported on 13 August 2019 that Rosatom is expected to receive about US$4 billion less in state funding for the construction of new nuclear reactors in Russia due to the postponement of its fast neutron reactor program – in particular, the postponement of commissioning of the proposed BN-1200 reactor to 2036 from the previous target of 2027.[373]

In 2014, Rosenergoatom spokesperson Andrey Timonov said the BN-800 reactor, which started up in 2014, "must answer questions about the economic viability of potential fast reactors because at the moment 'fast' technology essentially loses this indicator [when compared with] commercial VVER units."[374]

Russian plans in the 1980s to construct five BN-800 fast reactors in the Ural region failed to materialise and, as the International Panel on Fissile Materials noted in 2015, plans to scale up fast reactor deployment to 14 GW by 2030 and 34 GW by 2050 lack credibility.[375] Yet those implausible figures – 14 GW by 2030 and 34 GW by 2050 – are still promoted by the World Nuclear Association.[376]

The BREST-300 fast reactor project is stretching Rosatom's funds. Bellona's Alexander Nikitin said in 2014 that Rosatom's "Breakthrough" program to develop BREST-300 was only breaking Rosatom's piggy-bank.[377]

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[369] World Nuclear Association, Sept 2016, 'Fast Neutron Reactors', https://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx

[370] Vladimir Slivyak, December 2014, 'Russian Nuclear Industry Overview', http://earthlife.org.za/www/wp-content/uploads/2014/12/russian-nuc-ind-overview.pdf

[371] World Nuclear Association, 10 Aug 2016, 'Russia to build 11 new nuclear reactors by 2030', http://www.world-nuclear-news.org/NP-Russia-to-build-11-new-nuclear-reactors-by-2030-10081602.html

[372] ibid.

[373] World Nuclear Association, 13 August 2019, 'Rosatom postpones fast reactor project, report says', http://www.world-nuclear-news.org/Articles/Rosatom-postpones-fast-reactor-project-report-say

[374] World Nuclear Association, 16 April 2015, 'Russia postpones BN-1200 in order to improve fuel design', www.world-nuclear-news.org/NN-Russia-postpones-BN-1200-in-order-to-improve-fuel-design-16041502.html

[375] Shaun Burnie, 15 Dec 2015, 'Russian BN-800 fast breeder reactor connected to grid', http://fissilematerials.org/blog/2015/12/russian_bn-800_fast_breed.html

[376] https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx

[377] Alexander Nikitin, 5 May 2015, 'In a perpetual search for perpetuum mobile', http://bellona.org/news/uncategorized/2015-05-perpetual-search-perpetuum-mobile

China's program going nowhere fast

China has a 20 MWe experimental fast reactor, which operated for a total of less than one month in the 63 months from criticality in July 2010 to October 2015.[378] For every hour the reactor operated in 2015, it was offline for five hours, and there were three recorded reactor trips.[379]

Construction of the CFR600 demonstration fast reactor (CDFR) began in December 2017.[380]

China also has plans to build a 1,000 MWe commercial-scale fast reactor but that project has not yet been approved[381] and it would of course be another giant leap from a single commercial-scale fast reactor to a fleet of them.

According to the World Nuclear Association, a decision to proceed with or cancel the 1,000 MW fast reactor will not be made until 2020, and if it proceeds, construction could begin in 2028 and operation could begin in about 2034.[382]

So China might have one commercial-scale fast reactor by 2034 – but probably won't.

According to the World Nuclear Association, China envisages at least 200 GWe of fast reactor capacity by 2050, and 1,400 GWe by 2100.[383] Those projections should not be given any credence given that China has one poorly-performing, very small demonstration fast reactor, is in the early stages of construction of a larger demonstration fast reactor, and has not approved let alone built or operated a single commercial-scale fast reactor.

A future for fast reactors?

Apart from the countries mentioned above, there is very little interest in pursuing fast reactor technology. Germany, the UK and the US cancelled their prototype breeder reactors in the 1980s and 1990s.[384] Currently, five fast reactors are in operation, all of them classed as demonstration or experimental reactors. There is no likelihood of a significant expansion in the foreseeable future – indeed there is no likelihood that the number will reach double figures in the foreseeable future.

As discussed in the following appendix (on Integral Fast Reactors), plans for a Versatile Test Reactor based on PRISM fast reactor technology in the US are bizarre and improbable for several reasons.[385] The plan will almost certainly be abandoned, as was the case with the 'Next Generation Nuclear Plant Project' conceived in 2005 and abandoned in 2011.[386]

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[378] www.world-nuclear.org/info/country-profiles/countries-a-f/china--nuclear-power/

[379] Zhang Donghui / China Institute of Atomic Energy, 2016, 'Nuclear energy and Fast Reactor development in China', http://web.archive.org/web/20180114195620/www.iaea.org/NuclearPower/Downloadable/Meetings/2016/2016-05-16-05-20-NPES/3.1_China_49th_TWG-FR.pdf

[380] World Nuclear Association, Sept 2016, 'Fast Neutron Reactors', https://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx

[381] https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

[382] www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-fuel-cycle.aspx

[383] https://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx

[384] Thomas B. Cochran et al., 2010, 'Fast Breeder Reactor Programs: History and Status', http://fissilematerials.org/library/rr08.pdf

[385] World Nuclear Association, 15 Nov 2018, 'PRISM selected for US test reactor programme', http://www.world-nuclear-news.org/Articles/PRISM-selected-for-US-test-reactor-programme

[386] Nuclear Regulatory Commission, accessed 20 May 2019, 'Next Generation Nuclear Plant (NGNP)', https://www.nrc.gov/reactors/new-reactors/advanced/ngnp.html

APPENDIX 3: INTEGRAL FAST REACTORS (IFRS)

1. Whatever happened to the 'integral fast reactor'?

1.1 Introduction

A decade ago, nuclear lobbyists – including prominent champions such as climate scientist James Hansen and entrepreneur Richard Branson[387] – were heavily promoting 'integral fast reactors' (IFRs).

IFRs would, if they existed, share features of other fast neutron reactors along with some less common or distinctive features including metallic fuel and the coupling of the reactor to pyroprocessing. The fuel would sit in a pool of liquid metal sodium coolant, at atmospheric pressure. Pyroprocessing would not separate plutonium alone; it would instead separate plutonium mixed with other actinides, thus reducing proliferation risks compared to conventional PUREX reprocessing.

IFRs would (according to their advocates) solve all of nuclear power's problems, providing cheap power, proliferation-resistance, a dramatic reduction in the volume and longevity of radioactive waste, and the ability to use troublesome nuclear waste streams (actinides) and weapons material as fuel.

IFRs would (according to their advocates) end global warming. GE Hitachi's Eric Loewen was described as "the man who could end global warming" in *Esquire* magazine in 2009.[388]

Indeed IFRs would (according to their advocates) go a long way to solving all of the world's problems. *Esquire* magazine implored readers to consider the magnitude of the problems that Loewen was solving: "a looming series of biblical disasters that include global warming, mass starvation, financial collapse, resource wars, and a long-term energy crisis that's much more desperate than most of us realize."[2]

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[387] Mark Halper, 20 July 2012, 'Richard Branson urges Obama to back next-generation nuclear technology', https://www.theguardian.com/environment/2012/jul/20/richard-branson-obama-nuclear-technology
[388] John H. Richardson, 17 Nov. 2009, 'Meet the Man Who Could End Global Warming', https://www.esquire.com/news-politics/a6657/nuclear-waste-disposal-1209/

All of those claims should be traded with scepticism as discussed in section 4 below ('Integral fast reactors: fact and fiction'). But first, what has happened with IFRs over the past decade? In short, not much:

- The Canadian Nuclear Safety Commission is involved in pre-licensing vendor design reviews for numerous reactor concepts including the ARC-100 design, which is based on IFR technology.
- GE Hitachi is moving ahead at snail's pace in the US with its version of IFR technology, which it calls PRISM (Power Reactor Innovative Small Module), but no license application has been submitted to the US Nuclear Regulatory Commission (NRC).
- The US Department of Energy (DOE) is considering a bizarre and improbable plan to fund a PRISM reactor to be used as a test reactor to advance fast neutron reactor technology. The proposal will probably be abandoned, just as the 'Next Generation Nuclear Plant Project' initiated in 2005 was abandoned in 2011.
- The UK has formally abandoned consideration of IFR technology for plutonium disposition, and there is no longer any serious discussion about the potential use of IFRs for plutonium disposition in the US.
- In South Australia, nuclear lobbyists united behind a push to persuade the 2015/16 Nuclear Fuel Cycle Royal Commission of the merits of IFR/PRISM reactors. But the Royal Commission completely rejected the proposal, stating in its May 2016 report: "Fast reactors or reactors with other innovative designs are unlikely to be feasible or viable in South Australia in the foreseeable future. No licensed and commercially proven design is currently operating. Development to that point would require substantial capital investment. Moreover, the electricity generated has not been demonstrated to be cost-competitive with current light water reactor designs."[389]

1.2 IFR technology in Canada

Advanced Reactor Concepts (ARC) and New Brunswick Power have agreed to collaborate on the future deployment of an ARC-100 reactor at NB Power's Point Lepreau site in Canada.[390] ARC signed an agreement with GE Hitachi in 2017 to collaborate on development and licensing, and the ARC-100 design uses proprietary technology from GE Hitachi's PRISM design.[391] Whereas the PRISM design envisages twin 311 MW reactors feeding a single turbine, the ARC design is 100 MW, and another distinctive feature is that ARC-100 reactors would operate for up to 20 years without the need for refueling.

ARC is a company founded in 2006 and involves a number of people who were previously involved in the EBR-II reactor project – IFR R&D carried out at Argonne National Laboratory from the 1960s until the demonstration reactor was defunded and shut down in 1994 (with pyroprocessing work continuing to this day to address the legacy of nuclear waste … and probably continuing for decades into the future given that it has been a troubled and much-delayed project).

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[389] Nuclear Fuel Cycle Royal Commission Report, May 2016, http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf
[390] Advanced Reactor Concepts, https://www.arcnuclear.com/
World Nuclear Association, 10 July 2018, 'First partner announced for New Brunswick SMR project', http://www.world-nuclear-news.org/NN-First-partner-announced-for-New-Brunswick-SMR-project-1007187.html
Dan Yurman, 15 July 2018, 'Argonne's IFR to Live Again at Point Lepreau, New Brunswick', https://neutronbytes.com/2018/07/15/argonnes-ifr-to-live-again-at-point-lepreau-new-brunswick/
[391] Dan Yurman, 15 July 2018, 'Argonne's IFR to Live Again at Point Lepreau, New Brunswick', https://neutronbytes.com/2018/07/15/argonnes-ifr-to-live-again-at-point-lepreau-new-brunswick/

The Canadian Nuclear Safety Commission is currently involved in pre-licensing vendor design reviews for numerous small-reactor concepts including ARC-100. A Phase 1 assessment of the ARC-100 design has been ongoing since September 2017.[392]

The hope is that Point Lepreau will become a hub for a nuclear export industry. But no decision has been taken to build a demonstration reactor at Point Lepreau and any such decision is years away.[6] Construction of a demonstration reactor is no more than a "long-term vision" according to New Brunswick's energy minister Rick Doucet.[393]

Norman Sawyer, president of ARC Nuclear Canada, hopes that a single ARC-100 reactor could be built for C$1–1.5 billion.[394] But no-one is offering to stump up that sort of money. The Union of Concerned Scientists said the economics simply won't work:[395]
"The problem is that there is not sufficient private capital around to finance the development of even a single new non-light-water reactor, much less many different types. When you shrink the size of a nuclear reactor, you increase the unit cost of electricity because of those economies of scale."

Current funding – C$10 million from the New Brunswick provincial government (not all of it for ARC's project) and C$5 million from ARC – will only cover the vendor design review process. That process might (or might not) be followed by a much more exhaustive, expensive and time-consuming process to obtain a license to construct and operate an ARC-100 reactor.[396]

Brett Plummer, NB Power's vice-president for nuclear operations, said that there have only been preliminary talks about how a first reactor at Point Lepreau could be paid for, and he suggested the possibility of a public–private partnership.[397] In other words, vendors such as ARC have received government funding for preliminary regulatory design assessment, no doubt they will seek government funding to prepare a license to construct and operate a demonstration reactor, and they will then want government funding for reactor construction.

ARC has also received a grant from the UK government "to provide documentation intended to demonstrate the technical and business feasibility of the ARC-100 … and its licensability under U.K. nuclear safety regulations."[398] Perhaps the UK government should also provide a grant to another organisation to make the case that nuclear vendors should provide documentation at their own expense?

1.3 The long, slow march of IFR technology in the US

IFRs were the subject of the EBR-II R&D program in the US for several decades. That R&D program was not without controversy.[399] Dr. James Smith, a scientist who worked on an IFR R&D project in the US,

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[392] Connell Smith, 21 March 2019, 'Reactor developers propose a manufacturing hub – and a small nuclear plant', https://www.cbc.ca/news/canada/new-brunswick/lepreau-nuclear-energy-climate-change-spent-fuel-1.5063225
[393] Canadian Nuclear Association, 9 July 2018, 'New Brunswick should have second nuclear reactor: energy minister', https://cna.ca/news_cna/new-brunswick-should-have-second-nuclear-reactor-energy-minister/
[394] Connell Smith, 21 March 2019, 'Reactor developers propose a manufacturing hub – and a small nuclear plant', https://www.cbc.ca/news/canada/new-brunswick/lepreau-nuclear-energy-climate-change-spent-fuel-1.5063225
[395] Ibid.
[396] Ibid.
[397] Ibid.
[398] US Nuclear Regulatory Commission, Feb 1994, "Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor", https://www.nrc.gov/docs/ML0634/ML063410561.pdf
[399] www.faqs.org/abstracts/Zoology-and-wildlife-conservation/Fusion-programme-could-aid-terrorists-California-to-keep-energy-labs-contracts.html

was improperly pressured to resign from the project for raising concerns about defective work including fundamental errors in metallurgy and related sciences, at least some of which had safety implications. He further claimed that Argonne National Laboratory published false and misleading accounts of its work. The Office of Nuclear Safety concurred with Dr. Smith's claims that ANL failed to act on his proposals for improving how errors are detected.

Enthusiasts argue that IFR/PRISM reactor technology is ready to go on the basis of the EBR-II project at Argonne National Laboratory. It isn't. A 1994 pre-application safety evaluation report by the NRC stated:[400]
"Although all major problems are currently being addressed, much research remains to be performed in order to establish the safety and reliability of the specific fuel concept to the burnups planned. The data base to support the metal-fuel system to be used in the PRISM design needs to be developed. …
"The PRISM fuel system … is a new concept. Many of the basic design principles have been developed from EBR-II metal-fuel experience. However, because of differences in material, geometry, and exposure conditions, this experience must be extrapolated to the PRISM design through the use of analytical tools that characterize the operational history and transient responses of the fuel system. Experimental data must be obtained both to support the model development efforts and to verify the integrated computer codes. …
"Although no new major safety-related problems in the proposed PRISM fuel system design were identified, many phenomenological uncertainties must be resolved in order to develop a set of analytical tools and a supporting experimental data base necessary for licensing."

Plans to apply to the NRC for a construction and operation license have been floated periodically since 1994. GE Hitachi has completed the NRC's 'preapplication review process'[401], but no license application has been submitted.

In a March 2009 letter to the NRC, GE Hitachi indicated that it intended to submit a design application in mid-2011.[402] In 2011, Tom Blees, president of an IFR/PRISM lobby group called the Science Council for Global Initiatives, wrote: "The suggestion … that fast reactors are thirty years away is far from accurate. GE-Hitachi plans to submit the PRISM design to the Nuclear Regulatory Commission (NRC) next year for certification."[403] But GE Hitachi hasn't progressed beyond the pre-application review process.

Blees also claimed in 2011 that China was building a copy of the EBR-II IFR prototype.[404] That claim was false. If he was referring to the China Experimental Fast Reactor, it isn't an IFR clone, it took over a decade to build the 20 MW reactor, and it has been a failure.[405] If he was referring to TerraPower's

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www.osti.gov/energycitations/product.biblio.jsp?osti_id=6030509
www.nature.com/nature/journal/v356/n6369/pdf/356469a0.pdf
https://inis.iaea.org/search/search.aspx?orig_q=RN:23040624
[400] Ibid.
[401] Hitachi, 13 Nov 2018, 'GE Hitachi and PRISM Selected for U.S. Department of Energy's Versatile Test Reactor Program', http://www.hitachi-hgne.co.jp/en/news/2018/2018news03.html
[402] Duncan Williams, 20 Jan 2010, 'Under The Hood With Duncan Williams - GE Hitachi's PRISM Reactor', http://nuclearstreet.com/nuclear_power_industry_news/b/nuclear_power_news/archive/2010/01/20/under-the-hood-with-duncan-williams-ge-hitachi-prism-reactor-01201
[403] Tom Blees, 4 June 2011, 'Response to a consultation on the management of the UK's plutonium stocks', http://bravenewclimate.com/2011/06/04/uk-pu-cc/
[404] Ibid.
[405] Nuclear Monitor #831, 5 Oct 2016, 'The slow death of fast reactors', https://www.wiseinternational.org/nuclear-monitor/831/slow-death-fast-reactors

plan for a prototype fast neutron reactor in China, that plan has been abandoned due to restrictions placed on nuclear trade with China by the Trump administration.

Blees said in 2011 that work was in train to "facilitate a cooperative effort between GE-Hitachi and Rosatom to build the first PRISM reactor in Russia as soon as possible" and that "if the United States moves ahead with supporting a GE-Rosatom partnership, the first PRISM reactor could well be built within the space of the next five years".[406] Nothing came of that initiative.

Blees said in 2011 that the "Science Council for Global Initiatives is currently working on arranging for the building of the first commercial-scale facility in the USA for conversion of spent LWR fuel into metal fuel for fast reactors."[407] Nothing has come of that initiative.

In July 2017, Blees reported the 'good news' that GE Hitachi "finally is applying for a commercial license for the PRISM."[408] But there was no such application.

In October 2010, GE Hitachi signed a memorandum of understanding with the operators of the US DOE's Savannah River site to consider the construction of a demonstration PRISM reactor. It would be possible to construct a prototype without having completed the NRC's usual licensing procedures, as Savannah River is a federally-owned site.[409] But nothing came of that initiative.

In October 2016, GE Hitachi and US company Southern Nuclear announced their intention to collaborate on the development and licensing of PRISM reactor technology.[410] But little seems to have come from that initiative – the websites of GE Hitachi and Southern Nuclear have no information other than the October 2016 announcement. Pro-nuclear commentator Dan Yurman suggests that the companies "may be anticipating future grant programs".[411]

In June 2017, GE Hitachi said that a nuclear industry team was "collaborating to potentially seek a regulatory license to deploy GEH's advanced PRISM sodium-cooled fast reactor design."[412] The companies planned to pursue DOE advanced reactor projects based on public–private partnerships. In other words, they have their hands out for taxpayer subsidies.

To sum up … progress has been extraordinarily slow. One might have expected more interest if, as advocates claim, IFRs can solve all of nuclear power's problems and many of the world's most pressing

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Mark Hibbs, 17 Feb 2017, 'Rethinking China's Fast Reactor', http://www.armscontrolwonk.com/archive/1202830/rethinking-chinas-fast-reactor/

[406] Tom Blees, 4 June 2011, 'Response to a consultation on the management of the UK's plutonium stocks', http://bravenewclimate.com/2011/06/04/uk-pu-cc/

[407] Ibid.

[408] Tom Blees, 4 July 2017, 'Good News!', http://www.thesciencecouncil.com/index.php/tom-blees-president/315-good-news

[409] World Nuclear News, 28 Oct 2010, 'Prototype Prism proposed for Savannah River', http://www.world-nuclear-news.org/NN-Prototype_Prism_proposed_for_Savannah_River-2810104.html
Savannah River Nuclear Solutions, 2010 Annual Report, https://www.srs.gov/srns/docs/srns_2010_annual_report.pdf

[410] GE, 31 Oct 2016, 'GE Hitachi Nuclear Energy and Southern Nuclear to Collaborate on Advanced Reactor Development and Licensing', https://www.genewsroom.com/press-releases/ge-hitachi-nuclear-energy-and-southern-nuclear-collaborate-advanced-reactor

[411] Dan Yurman, 31 Oct 2016, 'Southern Signs On for the PRISM Advanced Reactor', http://neutronbytes.com/2016/10/31/southern-signs-on-for-the-prism-advanced-reactor/

[412] High Bridge Energy Development Company, 2 June 2017, 'Nuclear Industry Team Collaborating on Advanced Reactor Licensing and Development', https://gehitachiprism.com/nuclear-industry-team-collaborating-on-advanced-reactor-licensing-and-development/

problems. Interest in IFRs would have died altogether if not for a drip-feed of government funding stretching back decades:[413]

- The EBR-II R&D project was government funded, and ongoing work on pyroprocessing is DOE funded.
- 1985–87: US$30 million from the DOE to study liquid metal reactor concepts.
- 1988: US$5 million from the DOE for 'continuing trade studies'.
- 1989–95: US$42 million from the DOE for the Advanced Liquid Metal Reactor program.
- A multi-million-dollar grant from the DOE, announced in 2014, for GE Hitachi to carry out a PRISM safety assessment.[414]

The most recent development is that the NRC has been working with industry on the Licensing Modernization Project to develop "regulatory guidance for licensing non-LWRs for the NRC's consideration and possible endorsement". On the basis of that work, the NRC hopes to issue a final regulatory guide in late 2019.[415]

The Science Council for Global Initiatives continues with its bluff and bluster. Tom Blees claimed in November 2018 that:[416]
"SCGI is now deeply involved with expediting some of the most promising projects that we have been nurturing for several years. We would like to share all the details, but we are required to keep much of it confidential. What we can say is that our efforts to promote rapid construction of commercial-scale prototypes of three systems that could power the planet now involve the US, China, South Korea and others. The three systems are metal-fueled fast reactors, molten salt reactors, and the spent fuel recycling system called pyroprocessing."

Blees' claims would carry greater weight if not for his track record of promoting initiatives that never eventuated.

<u>1.4 'Versatile Test Reactor'</u>

In 2018, Idaho National Laboratory (INL) subcontracted GE Hitachi to work with Bechtel to advance design and cost estimates for a Versatile Test Reactor (VTR) based on PRISM technology.[417] According to INL, the reactor would facilitate the development of innovative nuclear fuels, materials, instrumentation and sensors.[418] The DOE plans to decide in 2020 whether or not to proceed with (and fund or part-fund) the project.

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[413] GE Hitachi, 7 June 2016, 'PRISM & U.S. Licensing', https://www.nrc.gov/public-involve/conference-symposia/adv-rx-non-lwr-ws/2016/21-loewen-prism.pdf
[414] Jenny Callison, 6 Nov 2014, 'GE Hitachi Receives Federal Funds To Assess New Nuclear Technology', http://www.wilmingtonbiz.com/technology/2014/11/06/ge_hitachi_receives_federal_funds_to_assess_new_nuclear_technology/12531
Tomas Kellner, 6 Nov 2014, 'This Advanced Nuclear Reactor Feasts on Radioactive Leftovers', http://www.gereports.com/post/101863876380/this-advanced-nuclear-reactor-feasts-on/
[415] NRC, accessed May 2019, 'Industry-Led Licensing Modernization Project', https://www.nrc.gov/reactors/new-reactors/advanced.html
[416] Tom Blees, Nov 2018, 'SCGI President's Message, November 2018', http://www.thesciencecouncil.com/index.php/about/founder-and-president/353-scgi-president-s-message-november-2018
[417] World Nuclear Association, 15 November 2018, 'PRISM selected for US test reactor programme', http://www.world-nuclear-news.org/Articles/PRISM-selected-for-US-test-reactor-programme
[418] INL, 13 Nov 2018, GE Hitachi Awarded Subcontract for Work Supporting Proposed Versatile Test Reactor, https://inl.gov/article/subcontract-awarded-for-versatile-test-reactor/

The proposal is bizarre – and improbable – for several reasons.

Firstly, fast reactor technology has failed in the US as it has in many other countries.[419] Why attempt a revival, especially in light of the hefty price-tag for the VTR – an estimated US$3.9–6.0 billion?[420]

Secondly, it makes little sense to choose a largely untested, experimental reactor type. The experimental reactor will itself be an experiment.

Thirdly, even if it was agreed that a fast-neutron test capability was needed, a new reactor isn't required. Ed Lyman from the Union of Concerned Scientists states:[421]
"In fact, there are ways to simulate the range of neutron speeds typical of a fast reactor in an already existing test reactor, such as the Advanced Test Reactor at Idaho National Laboratory or the High Flux Isotope Reactor at Oak Ridge National Laboratory. This could be accomplished by using neutron filters and possibly a different type of fuel. Going that route would be significantly cheaper: A 2009 DOE assessment suggests that this approach could achieve the minimum requirements necessary and would cost some $100 million to develop (in 2019 dollars), considerably less than the VTR project's projected price tag. Equally important, using one of the two currently operating test reactors could likely provide developers with fast neutrons more quickly than the VTR project."

Fourthly, if built the VTR would likely use plutonium driver fuel that is not only weapons-usable but weapons-grade.[422]

The VTR will most likely go the way of the 'Next Generation Nuclear Plant Project'. The DOE planned to build a prototype 'next generation' reactor to generate electricity, produce hydrogen, or both, by the end of fiscal year 2021. The project was initiated in 2005 but the DOE decided not to proceed with it in 2011, citing an impasse between the DOE and the NGNP Industry Alliance regarding cost-sharing arrangements.[423]

2. Integral fast reactors rejected for plutonium disposition in the UK

As Cumbrians Opposed to a Radioactive Environment (CORE) recently noted, it was in 2008 that the UK Nuclear Decommissioning Authority (NDA) released a Comment Paper on the options for managing the plutonium stockpile accumulating from the reprocessing of spent fuel at Sellafield – a stockpile estimated by the NDA to reach 140+ tonnes (in the form of plutonium oxide powder) when all reprocessing at Sellafield has ceased.[424]

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[419] International Panel on Fissile Materials, 17 Feb 2010, 'History and status of fast breeder reactor programs worldwide', http://fissilematerials.org/blog/2010/02/history_and_status_of_fas.html
Nuclear Monitor #831, 5 Oct 2016, 'The slow death of fast reactors', www.wiseinternational.org/nuclear-monitor/831/slow-death-fast-reactors
[420] Ed Lyman, 5 April 2019, 'There are Faster, Cheaper, Safer and More Reliable Alternatives to the Energy Department's Proposed Multibillion Dollar Test Reactor', https://allthingsnuclear.org/elyman/alternatives-to-multibillion-dollar-test-reactor
[421] Ibid.
[422] Edwin Lyman, 11 June 2018, 'UCS technical rebuttal to the Idaho National Laboratory's opinions on the Versatile (Fast) Test Reactor', https://s3.amazonaws.com/ucs-documents/global-security/Lyman-Response-INL-Justification.pdf
[423] Nuclear Regulatory Commission, accessed 20 May 2019, 'Next Generation Nuclear Plant (NGNP)', https://www.nrc.gov/reactors/new-reactors/advanced/ngnp.html
[424] CORE, 6 May 2019, 'A decision on the fate of UK's Plutonium stockpile remains years away', http://corecumbria.co.uk/briefings/a-decision-on-the-fate-of-uks-plutonium-stockpile-remains-years-away/

The NDA is years away from making a decision about how to dispose of the plutonium stockpile and/or to use it as reactor fuel. But the use of IFR/PRISM technology has been formally rejected. The NDA said in a March 2019 report:[425]

"The NDA considered a proposal by GE Hitachi Nuclear Energy (GEH) to build a fuel fabrication plant and two PRISM reactors to irradiate a plutonium alloy fuel. No PRISM reactors or fuel plants have ever been built, and the proposal considered by NDA therefore envisaged both the reactors and fuel plant being first of a kind.

"This approach had some theoretical benefits compared to the MOX options. PRISM fast reactors were put forward by GEH as commercially viable, "ready to deploy" and capable of quickly dispositioning the complete plutonium stockpile. However, the studies undertaken by NDA with GEH over the past few years have shown that a major research and development programme would be required, indicating a low level of technical maturity for the option with no guarantee of success.

"Whilst these R&D requirements are extensive, they are also reasonably well understood. However, the work needed for the fuel fabrication facility is considered preliminary and the proposal was based on not requiring further plutonium-active testing prior to scale-up and industrialisation. This major technical risk, based on GEH's proposal, would also be borne by the NDA. In addition, the regulatory review by the ONR and EA highlighted this approach as carrying significant licensing risks in all areas. Implementation scenarios were assessed as economically unfavourable compared to other options reflecting, in part, the technical and licensing uncertainties in the proposal.

"At this time, it is noted that the cost, scope and extent of work required to progress Fast Reactor options, such as the GEH PRISM, as well as the timeframe for these options to become available, means it is not credible for the NDA to develop these options, or have them available for implementation within the next 20 years. Therefore no further work with GEH has been funded by NDA. However, given the very long-term nature of any disposition programme, the NDA will continue to monitor Fast Reactor developments world-wide and assess levels of maturity and potential benefits."

Thus the NDA has reaffirmed views expressed in internal 2011 emails, released under Freedom of Information laws, that its "high-level assessment" of PRISM reactors for plutonium disposition found that "the technology maturity for the fuel, reactor and recycling plant are considered to all be low".[426]

The use of plutonium in MOX fuel for conventional light-water reactors or CANMOX fuel for CANDU EC-6 reactors remain under consideration by the NDA, but the prospects are not good. The use of plutonium in MOX fuel is the NDA's preferred option, but as the NDA's recent report states, "this [MOX] option carries significant risks and uncertainties since it is fundamentally dependent on the availability of suitable new reactors in the UK and the operators' willingness to use MOX fuel. As the overall design of a MOX plant depends on a number of reactor-specific factors, commitments from operators under suitable terms would be a pre-requisite to reaching a decision on this option."[427]

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[425] UK NDA (Nuclear Decommissioning Authority), March 2019, Progress on Plutonium Consolidation, Storage and Disposition, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/791046/Progress_on_Plutonium.pdf

[426] Rob Edwards, 24 Jan 2012, 'Plans for Sellafield plutonium reactor rejected', https://www.theguardian.com/environment/2012/jan/24/sellafield-plutonium-reactor-plans-rejected

[427] UK NDA (Nuclear Decommissioning Authority), March 2019, Progress on Plutonium Consolidation, Storage and Disposition, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/791046/Progress_on_Plutonium.pdf

The previous MOX plant at Sellafield suffered "many years of disappointing performance" according to the NDA's chief executive, and the decision to close the plant was announced in August 2011 as there were no longer any customers in the aftermath of the Fukushima disaster in Japan.[428]

As for the CANMOX option – the building of a CANMOX fuel plant and at least two CANDU EC-6 reactors – the NDA report states that this is a "credible" option but "no discernible evidence was offered that this approach would be significantly simpler or more cost-effective than reuse as MOX in LWRs." The NDA notes "greater technical and implementation risks" with CANMOX compared to MOX "largely due to the fact that production of CANMOX fuel has not been demonstrated on an industrial-scale. In addition, there are currently no CANDU reactors in operation which achieve the levels of fuel irradiation proposed by SNC Lavalin for this option."[429]

Given the poor prospects for using plutonium as reactor fuel, immobilisation followed by disposal may become the NDA's favoured option. Three immobilisation options are being studied: hot isostatic pressing to produce a monolithic ceramic product; a pressing and sintering process similar to MOX manufacturing to produce pellets; and encapsulation in cement-based matrices as used in the UK for Intermediate Level Wastes.[430]

3. Integral fast reactors rejected for plutonium disposition in the US

IFR/PRISM technology has also been rejected for plutonium disposition in the US. MOX has also been rejected – in part because of significant delays and cost overruns with a partially constructed and now abandoned MOX fuel fabrication plant in South Carolina. The US government favours a "dilute and dispose" option for disposing of 34 tonnes of plutonium: the Savannah River Site facility will be used to dilute plutonium and it will be disposed of at the WIPP repository in New Mexico.[431]

The US Department of Energy's (DOE) Plutonium Disposition Working Group released a report in 2014 which considered the use of Advanced Disposition Reactors (ADR) for plutonium disposition.[432] The ADR concept was similar to GE Hitachi's PRISM according to the DOE. The DOE's cost estimates for the use of ADRs for the processing of 34 tonnes of plutonium were as follows: 'capital project point estimate' US$9.4 billion; operating cost estimate US$33.4 billion; and other program costs US$7.6 billion. Thus the total would be "more than $58 billion life cycle cost when sunk costs cost are included." That was twice as much as the next most expensive option for plutonium management considered in the 2014 report.

The DOE report estimated that it would take 18 years to construct an ADR and associated facilities – despite claims from GE Hitachi and others that IFR/PRISM technology could be operational in as little as five years. The DOE report stated: "Final design of a commercial fast reactor would require significant

[428] Fiona Harvey, 3 Aug 2011, 'Sellafield Mox nuclear fuel plant to close', https://www.theguardian.com/environment/2011/aug/03/sellafield-mox-plant-close
[429] UK NDA (Nuclear Decommissioning Authority), March 2019, Progress on Plutonium Consolidation, Storage and Disposition, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/791046/Progress_on_Plutonium.pdf
[430] Ibid.
[431] World Nuclear Association, 16 May 2018, 'Perry scraps completion of US MOX facility', http://www.world-nuclear-news.org/UF-Perry-scraps-completion-of-US-MOX-facility-1605184.html
[432] US Department of Energy, April 2014, 'Report of the Plutonium Disposition Working Group: Analysis of Surplus Weapon Grade Plutonium Disposition Options', http://fissilematerials.org/library/doe14a.pdf

engineering and licensing and as such carries uncertainties in being able to complete within the assumed duration."[433]

On the technical challenges, the DOE report said:[434]
"Irradiation of plutonium fuel in fast reactors ... faces two major technical challenges: the first involves the design, construction, start-up, and licensing of a multi-billion dollar prototype modular, pool-type advanced fast-spectrum burner reactor; and the second involves the design and construction of the metal fuel fabrication in an existing facility. As with any initial design and construction of a first-of-a-kind prototype, significant challenges are endemic to the endeavor, however DOE has thirty years of experience with metal fuel fabrication and irradiation. The metal fuel fabrication facility challenges include: scale-up of the metal fuel fabrication process that has been operated only at a pilot scale, and performing modifications to an existing, aging, secure facility ... Potential new problems also may arise during the engineering and procurement of the fuel fabrication process to meet NRC's stringent Quality Assurance requirements for Nuclear Power Plants and Fuel Reprocessing Plants."

In short, the ADR option was associated with "significant technical risk" according to the DOE report, and metal fuel fabrication faces "significant technical challenges".

A review of the 2014 report, commissioned by the National Nuclear Security Administration and carried out by Aerospace, reached similar conclusions.[435] Commenting on its own assessment and the 2014 DOE report, Aerospace said:
"Both reports acknowledge the high technical and programmatic risks inherent in the necessary research and development, technology demonstration, full-scale design, construction, and startup of an advanced fast spectrum burner sodium cooled reactor. Both reports acknowledge that additional new facilities for metal fabrication will be required, incurring additional technical and programmatic risk. It is expected in both reports that the NRC licensing process and fuel qualification process will be lengthy.
"ADR is the most complex and technically challenging option. The Aerospace assessment notes significant issues with the industrial base, including the adequacy of the workforce, fast reactor knowledge base, and the need for a significant R&D and technology development and demonstration phase ...
"Long term storage of spent plutonium metal fuel rods may require a different approach than that used for spent commercial uranium fuel rods, and may require the development of a new facility.
"The ADR project is more technically challenging and complex than the MOX Fuel option. New facilities are needed for plutonium metal processing, fuel fabrication, and spent fuel storage. Execution of design and construction in an NRC licensing environment is new for advanced liquid metal reactors and will require hundreds of nuclear qualified suppliers and construction workers over a decade or more."

Aerospace commented on problems common to fast reactors:[436]
"Based on experience with existing fast reactors that utilize sodium as the reactor core coolant, fires and steam explosions have been major problems during operations. A number of plants have been shut down for long periods of time in the past as a result of sodium fires. A research report of the International Panel on Fissile Materials on fast reactor programs highlights the maintenance and repair challenges at fast reactors: "The reliability of light-water reactors has increased to the point where, on average, they operate at 80 percent of their generating capacity. By contrast, a large fraction of

[433] Ibid.
[434] Ibid.
[435] Aerospace, 20 Aug 2015, 'Plutonium Disposition Study Options Independent Assessment Phase 2 Report', prepared for National Nuclear Security Administration,
https://www.energy.gov/sites/prod/files/2018/02/f49/Plutonium_Disposition_Phase_2_TOR_082015_FINAL%5B1%5D.pdf
[436] Ibid.

sodium-cooled demonstration reactors have been shut down most of the time that they should have been generating electric power.""

Aerospace was also unimpressed by GE Hitachi's cost estimates:[437]
"Aerospace finds the quality and completeness of the cost basis of estimate is difficult to assess due to the age of the source data provided ... The ADR estimate also lacks costs associated with program-level risks that are likely to be encountered during development and operations. Therefore, the ADR program cost estimate reported in the 2014 [DOE] PWG report may be low relative to realized actual costs should the program proceed. It is very likely that the ADR program would be subject to funding constraints on capital and construction."

An August 2015 DOE Red Team report didn't even consider IFR/ADR technology worthy of detailed consideration:[438]
"The ADR option involves a capital investment similar in magnitude to the MFFF [Mixed Oxide Fuel Fabrication Facility] but with all of the risks associated with first of-a kind new reactor construction (e.g., liquid metal fast reactor), and this complex nuclear facility construction has not even been proposed yet for a Critical Decision (CD)-0. Choosing the ADR option would be akin to choosing to do the MOX approach all over again, but without a directly relevant and easily accessible reference facility/operation (such as exists for MOX in France) to provide a leg up on experience and design. Consequently, the remainder of this Red Team report focuses exclusively on the MOX approach and the Dilute and Dispose option, and enhancements thereof."

The DOE Red Team report said that the IFR/ADR option has "large uncertainties in siting, licensing, cost, technology demonstration, and other factors" but "could become more viable in the future" if fast reactors were to become part of the overall US nuclear energy strategy.

4. Integral fast reactors: fact and fiction

Integral fast reactors (IFR) would, if they existed, share features of other fast neutron reactors along with some less common or distinctive features including metallic fuel and the coupling of the reactor to pyroprocessing (discussed below). The fuel would sit in a pool of liquid metal sodium coolant, at atmospheric pressure.

IFR's have been the subject of endless hype but as Ed Lyman from the Union of Concerned Scientists notes, the interest of these "staunch advocates … has been driven largely by idealized studies on paper and not by facts derived from actual experience."[439]

Actual experience has been limited to the EBR-II prototype that operated at Argonne National Laboratory from the 1960s to 1994. Since then, progress has been glacial (see above: 'Whatever happened to the 'integral fast reactor').

For the most part, the claims of IFR advocates don't stand up to scrutiny.

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[437] Ibid.

[438] Thom Mason et al., 13 August 2015, 'Final Report of the Plutonium Disposition Red Team', for the US Department of Energy, https://www.energy.gov/sites/prod/files/2018/02/f49/Pu-Disposition-Red-Team-Report-081315vFinal-SM%5B1%5D.pdf

[439] Ed Lyman / Union of Concerned Scientists, 12 Aug 2017, 'The Pyroprocessing Files', http://allthingsnuclear.org/elyman/the-pyroprocessing-files

4.1 Safety

IFR advocates claim that:

- "Metal fuel expands if it overheats, shutting off the fission reaction and making a meltdown physically implausible."[440]
- "[E]ven a catastrophic situation will not result in a reactor meltdown".[441]
- GE Hitachi claims that: "In the event of a worst-case-scenario accident, the metallic core expands as the temperature rises, and its density decreases slowing the fission reaction. The reactor simply shuts itself down. PRISM's very conductive metal fuel and metal coolant then readily dissipates excess heat … without damaging any of its components. This is what is described as "passive safety" a design feature that relies upon the laws of physics, instead of human, electronic or mechanical intervention, to mitigate the risk of an accident."[442]

In fact, IFR/PRISM reactors would be subject to some of the same risks as other fast-reactor types[443] and other risks associated with pyroprocessing.

According to Argonne National Laboratory: "[T]he metal fuel technology base was developed at Argonne in the 1980s and 1990s; its inherent safety potential was demonstrated in the landmark tests conducted on the Experimental Breeder Reactor-II (EBR-II) in April 1986. They demonstrated the safe shutdown and cooling of the reactor without operator action following a simulated loss-of-cooling accident."[444]

But the 1986 test was a "dog-and-pony show" according to Ed Lyman:[445]
"And what about [Charles] Till's claim that the IFR can't melt down? It's false. "Pandora's Promise" referenced two successful safety tests conducted in 1986 at a small demonstration fast reactor in Idaho called the Experimental Breeder Reactor-II (EBR-II). But EBR-II operators scripted these tests to ensure the desired outcome, a luxury not available in the real world. Meanwhile, the EBR-II's predecessor, the EBR-I, had a partial fuel meltdown in 1955, and a similar reactor, Fermi 1 near Detroit, had a partial fuel meltdown in 1966. Moreover, fast reactors have inherent instabilities that make them far more dangerous than light-water reactors under certain accident conditions, conditions that were studiously avoided in the 1986 dog-and-pony show at EBR-II."

4.2 Nuclear weapons proliferation

Climate scientist James Hansen claims that IFR technology "could be inherently free from the risk of proliferation"[446] and another IFR proponent, Barry Brook, claims they "cannot be used to generate weapons-grade material."[447]

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[440] Mark Lynas, 1 March 2012, 'UK moves a step closer to nuclear waste solution', http://www.marklynas.org/2012/03/uk-moves-a-step-closer-to-nuclear-waste-solution/
[441] David Flin, 29 Jan 2017, 'PRISM: Waste not, want not', http://www.neimagazine.com/features/featureprism-waste-not-want-not-5726085/
[442] GE Hitachi, accessed 20 May 2019, 'Decades of innovation helped GEH create PRISM', https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/prism1
[443] Edwin Lyman, 11 June 2018, 'UCS technical rebuttal to the Idaho National Laboratory's opinions on the Versatile (Fast) Test Reactor', https://s3.amazonaws.com/ucs-documents/global-security/Lyman-Response-INL-Justification.pdf
[444] World Nuclear Association, 27 Aug 2014'Cooperation deal to develop advanced reactor', http://www.world-nuclear-news.org/NN-Cooperation-deal-to-develop-advanced-reactor-2708141.html
[445] Edwin Lyman, 7 Nov 2013, 'Scientist: Film hypes the promise of advanced nuclear technology', https://edition.cnn.com/2013/11/07/opinion/lyman-nuclear-pandora/index.html
[446] Kharecha, P. A.; Kutscher, C. F.; Hansen, J. E.; Mazria, E. 'Options for near-term phaseout of CO2 emissions from coal use in the United States'. Environ. Sci. Technol. 2010, 44, 4050-4062, http://pubs.acs.org/doi/abs/10.1021/es903884a

In fact, IFRs could be used to produce plutonium for weapons. Dr. George Stanford, who worked on the IFR (EBR-II) 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."[448] And IFR advocate Tom Blees notes that: "IFRs are certainly not the panacea that removes all threat of proliferation, and extracting plutonium from it would require the same sort of techniques as extracting it from spent fuel from light water reactors."[449]

IFR proponents claim they could help solve proliferation problems by using fissile material (especially plutonium) as reactor fuel. But they could also worsen proliferation problems. To quote from an Argonne National Laboratory report: "The reactor ... could be used for excess plutonium consumption or as a breeder if needed ..."[450]

IFR proponents claim that pyroprocessing does not pose a proliferation risk because the plutonium it separates from irradiated fuel is mixed with other (non-fissile) actinides. But a 2008 US Department of Energy review concluded that pyroprocessing and similar technologies would "greatly reduce barriers to theft, misuse or further processing, even without separation of pure plutonium."[451]

IFR advocates Barry Brook and Corey Bradshaw claim that nuclear weapons proliferation "is under strong international oversight."[452] Oddly, they cite another IFR advocate, Tom Blees, in support of that statement. But Blees doesn't argue that the nuclear industry *is* subject to strong international oversight − he argues that "fissile material *should* all be subject to rigorous international oversight" (emphasis added).[453]

Blees argues for the establishment of an international strike force on full standby to attend promptly to any detected attempts to misuse or to divert nuclear materials.[454] That is a far cry from the IAEA's safeguards system as it currently exists. In articles and speeches during his tenure as the Director General of the IAEA from 1997−2009, Dr. Mohamed ElBaradei said that the Agency's basic rights of inspection are "fairly limited", that the safeguards system suffers from "vulnerabilities" and "clearly needs reinforcement", that efforts to improve the system have been "half-hearted", and that the safeguards system operates on a "shoestring budget ... comparable to that of a local police department".

Some IFR proponents indulge in disingenuous comparisons. For example, it is fair to say that pyroprocessing poses less of a proliferation risk compared to conventional PUREX reprocessing … but it poses a greater proliferation risk compared to a once-through, no-reprocessing fuel cycle.

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[447] Barry Brook, 9 June 2009, 'An inconvenient solution', The Australian, http://bravenewclimate.com/2009/06/11/an-inconvenient-solution/

[448] George Stanford, 18 Sep 2010, 'IFR FaD 7 – Q&A on Integral Fast Reactors', http://bravenewclimate.com/2010/09/18/ifr-fad-7/

[449] http://bravenewclimate.com/2009/02/12/integral-fast-reactors-for-the-masses/

[450] Harold F. McFarlane, Argonne National Laboratory, 'Proliferation Resistance Assessment Of The Integral Fast Reactor', www.ipd.anl.gov/anlpubs/2002/07/43534.pdf

[451] Edwin Lyman, 7 Nov 2013, 'Scientist: Film hypes the promise of advanced nuclear technology', https://edition.cnn.com/2013/11/07/opinion/lyman-nuclear-pandora/index.html

[452] Brook, B. W., and C. J. A. Bradshaw. 2014. Key role for nuclear energy in global biodiversity conservation. Conservation Biology. http://dx.doi.org/10.1111/cobi.12433

[453] Barry Brook, 2009, 'Response to an Integral Fast Reactor (IFR) critique', http://bravenewclimate.com/2009/02/21/response-to-an-integral-fast-reactor-ifr-critique/

[454] Blees T. 2008. 'Prescription for the planet: the painless remedy for our energy & environmental crises'. http://www.thesciencecouncil.com/pdfs/P4TP4U.pdf

4.3 Economics

GE Hitachi refuses to release estimates of capital and operating costs for its IFR design (which it calls PRISM), saying they are "commercially sensitive".[455]

Other IFR advocates aren't so shy about offering (implausible) estimates for IFRs. Steve Kirsch states that the first PRISM reactor "will probably cost around [US]$1 to $2 billion" per 1,000 MW.[456] That would make PRISM up to 13 times cheaper (per MW) than the Vogtle AP1000 project in the US.

Tom Blees states that the cost of the first PRISM reactor would be in the range of US$3–4 billion[457] (US$4.8–6.2 billion / 1,000 MW assuming the estimate is for a twin-reactor block with a capacity of 622 MW).

Future (nth-of-a-kind) PRISMs have reportedly been estimated by GE Hitachi to cost about US$1.7 billion / 1,000 MW[458] – radically cheaper than Lazard's latest estimate of US$6.5–12.5 billion / 1,000 MW for new nuclear plants.[459]

James Hansen, Richard Branson and GE Hitachi's Eric Loewen claimed in 2012 that IFRs could generate electricity "at a cost per kW less than coal"[460] (roughly 2–3 times cheaper than Lazard's latest estimate of the cost of electricity from new nuclear plants[461]). Dr. Hansen may have been closer to the mark in 2008 when he said: "I do not have the expertise or insight to evaluate the cost and technology readiness estimates" of IFR advocate Tom Blees and the "overwhelming impression that I get ... is that Blees is a great optimist."[462]

4.4 Waste

Here are some of the claims made by IFR advocates:

- GE Hitachi: "In GEH's view, what is generally considered to be "nuclear waste" these days is not really waste at all. Light Water Reactor (LWR) used nuclear fuel is composed of 95 percent uranium, 1 percent transuranics, and 4 percent fission products. Many of these transuranic isotopes have long half-lives, which can create long-term engineering challenges for geologic disposal. By using electro-metallurgical separations, PRISM is designed to perform the recycling of the 96 percent of the fissionable material (uranium and transuranics) remaining in used nuclear fuel."[463]
- George Monbiot: "IFRs, once loaded with nuclear waste, can, in principle, keep recycling it until only a small fraction remains, producing energy as they do so. The remaining waste ... presents

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455 GE Hitachi, accessed 20 May 2019, 'Frequently Asked', http://gehitachiprism.com/faqs/
456 Steve Kirsch, accessed 22 May 2019, 'The Integral Fast Reactor (IFR) project: Q&A', http://skirsch.com/politics/globalwarming/ifrQandA.htm
457 Tom Blees, 4 June 2011, 'Response to a consultation on the management of the UK's plutonium stocks', http://bravenewclimate.com/2011/06/04/uk-pu-cc
458 ibid.
459 Lazard, Nov 2018, 'Lazard's Levelized Cost of Energy Analysis – Version 12.0', https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf
460 Mark Halper, 20 July 2012, 'Richard Branson urges Obama to back next-generation nuclear technology', https://www.theguardian.com/environment/2012/jul/20/richard-branson-obama-nuclear-technology
461 Lazard, Nov 2018, 'Lazard's Levelized Cost of Energy Analysis – Version 12.0', https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf
462 James Hansen, 2008, 'Trip Report – Nuclear Power', http://www.columbia.edu/~jeh1/mailings/20080804_TripReport.pdf
463 GE Hitachi, accessed 20 May 2019, 'Decades of innovation helped GEH create PRISM', https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/prism1

much less of a long-term management problem, as its components have half-lives of tens, not millions, of years."[464]

- Mark Lynas: "For me, the most compelling reason to look seriously at the PRISM is that it can burn all the long-lived actinides in spent nuclear fuel, leaving only fission products with a roughly 300-year radioactive lifetime. This puts a very different spin on the eventual need for a geological repository – instead of something that will be designed to safeguard radioactive material for a million years (technically a very improbable idea), safeguarding waste for 300 years is a very different, and much less challenging, proposition."[465]
- Monbiot, Lynas, Fred Pearce, Stephen Tindale and Michael Hanlon: "The PRISM reactor offered by GE-Hitachi [is] a fourth-generation fast reactor design which can generate zero-carbon power by consuming our plutonium and spent fuel stockpiles, thereby tackling both the nuclear waste and climate problems simultaneously ..."[466]
- James Hansen: "Nuclear "waste": it is not waste, it is fuel for 4th generation reactors! … 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."[467]

But even if IFRs worked as hoped, they would still leave residual actinides, and long-lived fission products, and long-lived intermediate-level waste in the form of reactor and reprocessing components ... all of it requiring deep geological disposal. UC Berkeley nuclear engineer Prof. Per Peterson notes in an article published by the pro-nuclear Breakthrough Institute: "Even integral fast reactors (IFRs), which recycle most of their waste, leave behind materials that have been contaminated by transuranic elements and so cannot avoid the need to develop deep geologic disposal."[468]

4.5 Pyroprocessing

According to Tom Blees from the Science Council for Global Initiatives, pyroprocessing – a form of spent fuel reprocessing that dissolves metal-based spent fuel in a molten salt bath – is "proven" technology.[469]

But if pyroprocessing has been 'proven', it has proven to be a failure. The IFR (EBR-II) R&D program in the US left a legacy of troublesome waste and pyroprocessing has worsened the situation. This saga is discussed in detail by Ed Lyman, drawing on documents released under the Freedom of Information Act.[470]

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[464] George Monbiot, 2 Feb 2012, 'We cannot wish Britain's nuclear waste away', www.theguardian.com/environment/georgemonbiot/2012/feb/02/nuclear-waste

[465] Mark Lynas, 1 March 2012, 'UK moves a step closer to nuclear waste solution', http://www.marklynas.org/2012/03/uk-moves-a-step-closer-to-nuclear-waste-solution/

[466] A Letter to David Cameron, 15 March 2012, www.monbiot.com/2012/03/15/a-letter-to-david-cameron/

[467] James Hansen, 2011, 'Baby Lauren and the Kool-Aid', www.columbia.edu/~jeh1/mailings/2011/20110729_BabyLauren.pdf

[468] Breakthrough Institute, 5 May 2014, 'Cheap Nuclear', http://theenergycollective.com/breakthroughinstitut/376966/cheap-nuclear

[469] Tom Blees, Nov 2018, 'SCGI President's Message, November 2018', http://www.thesciencecouncil.com/index.php/about/founder-and-president/353-scgi-president-s-message-november-2018

[470] Ed Lyman / Union of Concerned Scientists, 12 Aug 2017, 'The Pyroprocessing Files', http://allthingsnuclear.org/elyman/the-pyroprocessing-files

Ed Lyman, 2017, 'External Assessment of the U.S. Sodium-Bonded Spent Fuel Treatment Program', https://s3.amazonaws.com/ucs-documents/nuclear-power/Pyroprocessing/IAEA-CN-245-492%2Blyman%2Bfinal.pdf

Lyman states:[471]
"[P]yroprocessing has taken one potentially difficult form of nuclear waste and converted it into multiple challenging forms of nuclear waste. DOE has spent hundreds of millions of dollars only to magnify, rather than simplify, the waste problem. …
"The FOIA documents we obtained have revealed yet another DOE tale of vast sums of public money being wasted on an unproven technology that has fallen far short of the unrealistic projections that DOE used to sell the project …
"Everyone with an interest in pyroprocessing should reassess their views given the real-world problems experienced in implementing the technology over the last 20 years at INL. They should also note that the variant of the process being used to treat the EBR-II spent fuel is less complex than the process that would be needed to extract plutonium and other actinides to produce fresh fuel for fast reactors. In other words, the technology is a long way from being demonstrated as a practical approach for electricity production."

4.6 Ready to deploy?

GE Hitachi claims that "after 30 years of development, the technology utilized by PRISM is ready to be commercialized".[472] But government agencies in the US and the UK have reached radically different conclusions (see above: 'Integral fast reactors rejected for plutonium disposition in the UK' and 'Integral fast reactors rejected for plutonium disposition in the US').

GE Hitachi claims:[473]
"PRISM has successfully been through detailed regulatory review in the U.S. In its Report, "Pre-application Safety Evaluation: Report for the Power Reactor Innovative Small Module (PRISM) Liquid Metal Reactor," the U.S. Nuclear Regulatory Commission (NRC) stated: "On the basis of the review performed, the staff, with the ACRS in agreement, concludes that no obvious impediments to licensing the PRISM design have been identified.""

In fact, the NRC was much more downbeat, stating that "many … uncertainties must be resolved in order to develop a set of analytical tools and a supporting experimental data base necessary for licensing."[474]

Tom Blees argued in 2011 that the first IFR/PRISM reactor could be built in the US "within the space of the next five years" and that "far from being decades away, a fully-developed fast reactor design is ready to be built."[475] But no such reactors have been built – and GE Hitachi has not even submitted a license application.

British IFR advocate Mark Lynas said in 2012: "GE's executives told me that they could get one up and running in 5 years – the PRISM is fully proven in engineering terms and basically ready to go."[476] If

[471] Ed Lyman / Union of Concerned Scientists, 12 Aug 2017, 'The Pyroprocessing Files', http://allthingsnuclear.org/elyman/the-pyroprocessing-files
[472] GE Hitachi, accessed 20 May 2019, 'Frequently Asked', http://gehitachiprism.com/faqs/
[473] GE Hitachi, accessed 20 May 2019, 'Frequently Asked', http://gehitachiprism.com/faqs/
[474] US Nuclear Regulatory Commission, Feb 1994, "Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor", https://www.nrc.gov/docs/ML0634/ML063410561.pdf
[475] Tom Blees, 4 June 2011, 'Response to a consultation on the management of the UK's plutonium stocks', http://bravenewclimate.com/2011/06/04/uk-pu-cc/
[476] Mark Lynas, 1 March 2012, 'UK moves a step closer to nuclear waste solution', http://www.marklynas.org/2012/03/uk-moves-a-step-closer-to-nuclear-waste-solution/

that's what GE executives said, they were not being truthful and Lynas ought to have been more sceptical. The UK Nuclear Decommissioning Authority is no longer considering IFR/PRISM reactors for plutonium disposition, stating in a March 2019 report that "the studies undertaken by NDA with GEH over the past few years have shown that a major research and development programme would be required, indicating a low level of technical maturity for the option with no guarantee of success."[477]

In South Australia, nuclear lobbyists united behind a push to persuade the 2015/16 Nuclear Fuel Cycle Royal Commission of the merits of IFR/PRISM reactors. But the Royal Commission rejected the proposal, stating in its May 2016 report:[478]
"Fast reactors or reactors with other innovative designs are unlikely to be feasible or viable in South Australia in the foreseeable future. No licensed and commercially proven design is currently operating. Development to that point would require substantial capital investment. Moreover, the electricity generated has not been demonstrated to be cost-competitive with current light water reactor designs."

[477] UK NDA (Nuclear Decommissioning Authority), March 2019, Progress on Plutonium Consolidation, Storage and Disposition, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/791046/Progress_on_Plutonium.pdf
[478] Nuclear Fuel Cycle Royal Commission Report, May 2016, http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf

APPENDIX 4: FUSION SCIENTIST DEBUNKS FUSION POWER

The *Guardian's* science correspondent reported on 9 March 2018 that the dream of nuclear fusion is on the brink of being realised according to a major new US initiative that says it will put fusion power on the grid within 15 years.[479] Prof Maria Zuber, MIT's vice-president for research, said that the development could represent a major advance in tackling climate change. "At the heart of today's news is a big idea – a credible, viable plan to achieve net positive energy for fusion," she said. "If we succeed, the world's energy systems will be transformed. We're extremely excited about this."

However it can be said with confidence that the MIT is talking nonsense. Fusion faces huge – possibly insurmountable – obstacles that won't be solved with an over-excited MIT media release.

In 2017, the *Bulletin of the Atomic Scientists* published a detailed critique of fusion power written by Dr. Daniel Jassby, a former principal research physicist at the Princeton Plasma Physics Lab with 25 years experience working in areas of plasma physics and neutron production related to fusion energy.[480]

Dr. Jassby wrote:
"[U]nlike what happens in solar fusion – which uses ordinary hydrogen – Earth-bound fusion reactors that burn neutron-rich isotopes have byproducts that are anything but harmless: Energetic neutron streams comprise 80 percent of the fusion energy output of deuterium-tritium reactions and 35 percent of deuterium-deuterium reactions.
"Now, an energy source consisting of 80 percent energetic neutron streams may be the perfect neutron source, but it's truly bizarre that it would ever be hailed as the ideal electrical energy source. In fact, these neutron streams lead directly to four regrettable problems with nuclear energy: radiation damage to structures; radioactive waste; the need for biological shielding; and the potential for the production of weapons-grade plutonium 239 – thus adding to the threat of nuclear weapons proliferation, not lessening it, as fusion proponents would have it.
"In addition, if fusion reactors are indeed feasible – as assumed here – they would share some of the other serious problems that plague fission reactors, including tritium release, daunting coolant demands, and high operating costs. There will also be additional drawbacks that are unique to fusion devices: the use of fuel (tritium) that is not found in nature and must be replenished by the reactor itself; and unavoidable on-site power drains that drastically reduce the electric power available for sale."

All of these problems are endemic to any type of magnetic confinement fusion or inertial confinement fusion reactor that is fueled with deuterium-tritium or deuterium alone. The deuterium-tritium reaction is favored by fusion developers. Dr. Jassby notes that tritium consumed in fusion can theoretically be fully regenerated in order to sustain the nuclear reactions, by using a lithium blanket, but full regeneration is not possible in practice for reasons explained in his article.

Dr. Jassby wrote:
"To make up for the inevitable shortfalls in recovering unburned tritium for use as fuel in a fusion reactor, fission reactors must continue to be used to produce sufficient supplies of tritium – a situation which implies a perpetual dependence on fission reactors, with all their safety and nuclear proliferation

[479] Hannah Devlin, 9 March 2018, 'Carbon-free fusion power could be 'on the grid in 15 years'', https://www.theguardian.com/environment/2018/mar/09/nuclear-fusion-on-brink-of-being-realised-say-mit-scientists
[480] Daniel Jassby, 19 April 2017, 'Fusion reactors: Not what they're cracked up to be', Bulletin of the Atomic Scientists, https://thebulletin.org/2017/04/fusion-reactors-not-what-theyre-cracked-up-to-be/

problems. Because external tritium production is enormously expensive, it is likely instead that only fusion reactors fueled solely with deuterium can ever be practical from the viewpoint of fuel supply. This circumstance aggravates the problem of nuclear proliferation ..."

Weapons proliferation

Fusion reactors could be used to produce plutonium-239 for weapons "simply by placing natural or depleted uranium oxide at any location where neutrons of any energy are flying about" in the reactor interior or appendages to the reaction vessel, Dr. Jassby states.

Tritium breeding is not required in systems based on deuterium-deuterium reactions, so all the fusion neutrons are available for any use including the production of plutonium-239 for weapons – hence Dr. Dr. Jassby's comment about deuterium-deuterium systems posing greater proliferation risks than deuterium-tritium systems. He wrote: "In effect, the reactor transforms electrical input power into "free-agent" neutrons and tritium, so that a fusion reactor fueled with deuterium-only can be a singularly dangerous tool for nuclear proliferation."

Further, tritium itself is a proliferation risk – it is used to enhance the efficiency and yield of fission bombs and the fission stages of hydrogen bombs in a process known as "boosting", and tritium is also used in the external neutron initiators for such weapons. "A reactor fueled with deuterium-tritium or deuterium-only will have an inventory of many kilograms of tritium, providing opportunities for diversion for use in nuclear weapons," Dr. Jassby wrote.

It isn't mentioned in Dr. Jassby's article, but fusion has already contributed to proliferation problems even though it has yet to generate a single Watt of useful electricity. According to Khidhir Hamza, a senior nuclear scientist involved in Iraq's weapons program in the 1980s: "Iraq took full advantage of the IAEA's recommendation in the mid 1980s to start a plasma physics program for "peaceful" fusion research. We thought that buying a plasma focus device ... would provide an excellent cover for buying and learning about fast electronics technology, which could be used to trigger atomic bombs."[481]

Other problems

Another problem is the "huge" **parasitic power consumption** of fusion systems – "they consume a good chunk of the very power that they produce ... on a scale unknown to any other source of electrical power." There are two classes of parasitic power drain – a host of essential auxiliary systems that must be maintained continuously even when the fusion plasma is dormant (of the order of 75–100 MW), and power needed to control the fusion plasma in magnetic confinement fusion systems or to ignite fuel capsules in pulsed inertial confinement fusion systems (at least 6% of the fusion power generated). Thus a 300 MWt / 120 MWe system barely supplies on-site needs and thus fusion reactors would need to be much larger to overcome this problem of parasitic power consumption.

The **neutron radiation damage** in the solid vessel wall of a fusion reactor is expected to be worse than in fission reactors because of the higher neutron energies, potentially putting the integrity of the reaction vessel in peril.

Fusion fuel assemblies will be transformed into tons of **radioactive waste** to be removed annually from each reactor. Structural components would need to be replaced periodically thus generating "huge

[481] Khidhir Hamza, Sep/Oct 1998, 'Inside Saddam's Secret Nuclear Program', Bulletin of the Atomic Scientists, Vol. 54, No. 5, https://books.google.com.au/books?id=rwsAAAAAMBAJ

masses of highly radioactive material that must eventually be transported offsite for burial", and non-structural components inside the reaction vessel and in the blanket will also become highly radioactive by neutron activation.

Molten lithium presents a **fire and explosion hazard**, introducing a drawback common to liquid-metal cooled fission reactors.

Tritium leakage is another problem. Dr. Jassby wrote:
"Corrosion in the heat exchange system, or a breach in the reactor vacuum ducts could result in the release of radioactive tritium into the atmosphere or local water resources. Tritium exchanges with hydrogen to produce tritiated water, which is biologically hazardous. Most fission reactors contain trivial amounts of tritium (less than 1 gram) compared with the kilograms in putative fusion reactors. But the release of even tiny amounts of radioactive tritium from fission reactors into groundwater causes public consternation. Thwarting tritium permeation through certain classes of solids remains an unsolved problem."

Water consumption is another problem. Dr. Jassby wrote:
"In addition, there are the problems of coolant demands and poor water efficiency. A fusion reactor is a thermal power plant that would place immense demands on water resources for the secondary cooling loop that generates steam as well as for removing heat from other reactor subsystems such as cryogenic refrigerators and pumps. ... In fact, a fusion reactor would have the lowest water efficiency of any type of thermal power plant, whether fossil or nuclear. With drought conditions intensifying in sundry regions of the world, many countries could not physically sustain large fusion reactors."

Due to all of the aforementioned problems, and others, "any fusion reactor will face outsized **operating costs**." Whereas fission reactors typically require around 500 employees, fusion reactors would require closer to 1,000 employees. Dr. Jassby states that it "is inconceivable that the total operating costs of a fusion reactor will be less than that of a fission reactor".

Dr. Jassby concluded:
"To sum up, fusion reactors face some unique problems: a lack of natural fuel supply (tritium), and large and irreducible electrical energy drains to offset. Because 80 percent of the energy in any reactor fueled by deuterium and tritium appears in the form of neutron streams, it is inescapable that such reactors share many of the drawbacks of fission reactors – including the production of large masses of radioactive waste and serious radiation damage to reactor components. ...
"If reactors can be made to operate using only deuterium fuel, then the tritium replenishment issue vanishes and neutron radiation damage is alleviated. But the other drawbacks remain – and reactors requiring only deuterium fueling will have greatly enhanced nuclear weapons proliferation potential."
"These impediments – together with colossal capital outlay and several additional disadvantages shared with fission reactors – will make fusion reactors more demanding to construct and operate, or reach economic practicality, than any other type of electrical energy generator.
"The harsh realities of fusion belie the claims of its proponents of "unlimited, clean, safe and cheap energy." Terrestrial fusion energy is not the ideal energy source extolled by its boosters, but to the contrary: It's something to be shunned."

ITER test reactor

In addition to the critical analysis summarised above, fusion scientist Dr. Daniel Jassby has written a separate article in the *Bulletin of the Atomic Scientists* concentrating on the International Thermonuclear Experimental Reactor (ITER) under construction in Cadarache, France.[482]

Dr. Jassby notes that plasma physicists regard ITER as the first magnetic confinement device that can possibly demonstrate a "burning plasma," where heating by alpha particles generated in fusion reactions is the dominant means of maintaining the plasma temperature. However he sees four "possibly irremediable drawbacks": electricity consumption, tritium fuel losses, neutron activation, and cooling water demand.

Electricity consumption: The "massive energy investment" to half-build ITER "has been largely provided by fossil fuels, leaving an unfathomably large 'carbon footprint' for site preparation and construction of all the supporting facilities, as well as the reactor itself." ITER is a test reactor and will never generate electricity so that energy investment will never be repaid.

And when ITER is operating (assuming it reaches that stage), a large power input would be required. For a comparable power-producing reactor, a large power output would be necessary just to break even. Power inputs are required for a host of essential auxiliary systems which must be maintained even when the fusion plasma is dormant. In the case of ITER, that non-interruptible power drain varies between 75 and 110 MW(e). A second category of power drain revolves directly around the plasma itself – for ITER, at least 300 MW(e) will be required for tens of seconds to heat the reacting plasma while during the 400-second operating phase, about 200 MW(e) will be needed to maintain the fusion burn and control the plasma's stability.

Dr. Jassby noted that ITER personnel have corrected misleading claims such as the assertion that "ITER will produce 500 megawatts of output power with an input power of 50 megawatts." The 500 megawatts of output refers to fusion power (embodied in neutrons and alphas), which has nothing to do with electric power. The input of 50 MW is the heating power injected into the plasma to help sustain its temperature and current, and is only a small fraction of the overall electric input power to the reactor (300–400 MW(e)).

Tritium: "The most reactive fusion fuel is a 50-50 mixture of the hydrogen isotopes deuterium and tritium; this fuel (often written as "D-T") has a fusion neutron output 100 times that of deuterium alone and a spectacular increase in radiation consequences. ... While fusioneers blithely talk about fusing deuterium and tritium, they are in fact intensely afraid of using tritium for two reasons: First, it is somewhat radioactive, so there are safety concerns connected with its potential release to the environment. Second, there is unavoidable production of radioactive materials as D-T fusion neutrons bombard the reactor vessel, requiring enhanced shielding that greatly impedes access for maintenance and introducing radioactive waste disposal issues."

Tritium supply is likely to be problematic and expensive: "As ITER will demonstrate, the aggregate of unrecovered tritium may rival the amount burned and can be replaced only by the costly purchase of tritium produced in fission reactors."

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[482] Daniel Jassby, 14 Feb 2018, 'ITER is a showcase ... for the drawbacks of fusion energy', https://thebulletin.org/2018/02/iter-is-a-showcase-for-the-drawbacks-of-fusion-energy/

Tritium could be produced in the reactor by absorbing the fusion neutrons in lithium completely surrounding the reacting plasma, but "even that fantasy totally ignores the tritium that's permanently lost in its globetrotting through reactor subsystems."

Radioactive waste. "[W]hat fusion proponents are loathe to tell you is that this fusion power is not some benign solar-like radiation but consists primarily (80 percent) of streams of energetic neutrons whose only apparent function in ITER is to produce huge volumes of radioactive waste as they bombard the walls of the reactor vessel and its associated components. ... A long-recognized drawback of fusion energy is neutron radiation damage to exposed materials, causing swelling, embrittlement and fatigue. As it happens, the total operating time at high neutron production rates in ITER will be too small to cause even minor damage to structural integrity, but neutron interactions will still create dangerous radioactivity in all exposed reactor components, eventually producing a staggering 30,000 tons of radioactive waste."

Water consumption: "ITER will demonstrate that fusion reactors would be much greater consumers of water than any other type of power generator, because of the huge parasitic power drains that turn into additional heat that needs to be dissipated on site. ... In view of the decreasing availability of freshwater and even cold ocean water worldwide, the difficulty of supplying coolant water would by itself make the future wide deployment of fusion reactors impractical."

The pumps used to circulate cooling water will require a power supply of as much as 56 MW(e).

Conclusions: Dr. Jassby concludes with some critical comments on conventional, fusion and fast breeder reactors:
"Critics charge that international collaboration has greatly amplified the cost and timescale but the $20-to-30 billion cost of ITER is not out of line with the costs of other large nuclear enterprises, such as the power plants that have been approved in recent years for construction in the United States (Summer and Vogtle) and Western Europe (Hinkley and Flamanville), and the US MOX nuclear fuel project in Savannah River. All these projects have experienced a tripling of costs and construction timescales that ballooned from years to decades. The underlying problem is that all nuclear energy facilities – whether fission or fusion – are extraordinarily complex and exorbitantly expensive. ...
"ITER will be, manifestly, a havoc-wreaking neutron source fueled by tritium produced in fission reactors, powered by hundreds of megawatts of electricity from the regional electric grid, and demanding unprecedented cooling water resources. Neutron damage will be intensified while the other characteristics will endure in any subsequent fusion reactor that attempts to generate enough electricity to exceed all the energy sinks identified herein.
"When confronted by this reality, even the most starry-eyed energy planners may abandon fusion. Rather than heralding the dawn of a new energy era, it's likely instead that ITER will perform a role analogous to that of the fission fast breeder reactor, whose blatant drawbacks mortally wounded another professed source of "limitless energy" and enabled the continued dominance of light-water reactors in the nuclear arena."

APPENDIX 5: THORIUM

There is a great deal of rhetoric regarding thorium. This, for example:[483]
"Thorium is a superior nuclear fuel to uranium in almost every conceivable way ... If there is such a thing as green nuclear power, thorium is it. ... For one, a thorium-powered nuclear reactor can never undergo a meltdown. It just can't. ... Thorium is also thoroughly useless for making nuclear weapons. ... But wait, there's more. Thorium doesn't only produce less waste, it can be used to <u>*consume*</u> *existing waste."*

Those claims do not stand up to scrutiny.

Readiness

The World Nuclear Association (WNA) notes that the commercialisation of thorium fuels faces some "significant hurdles in terms of building an economic case to undertake the necessary development work." The WNA states:[484]
"A great deal of testing, analysis and licensing and qualification work is required before any thorium fuel can enter into service. This is expensive and will not eventuate without a clear business case and government support. Also, uranium is abundant and cheap and forms only a small part of the cost of nuclear electricity generation, so there are no real incentives for investment in a new fuel type that may save uranium resources.
"Other impediments to the development of thorium fuel cycle are the higher cost of fuel fabrication and the cost of reprocessing to provide the fissile plutonium driver material. The high cost of fuel fabrication (for solid fuel) is due partly to the high level of radioactivity that builds up in U-233 chemically separated from the irradiated thorium fuel. Separated U-233 is always contaminated with traces of U-232 which decays (with a 69-year half-life) to daughter nuclides such as thallium-208 that are high-energy gamma emitters. Although this confers proliferation resistance to the fuel cycle by making U-233 hard to handle and easy to detect, it results in increased costs. There are similar problems in recycling thorium itself due to highly radioactive Th-228 (an alpha emitter with two-year half life) present."

A 2012 report by the UK National Nuclear Laboratory states:[485]
"NNL has assessed the Technology Readiness Levels (TRLs) of the thorium fuel cycle. For all of the system options more work is needed at the fundamental level to establish the basic knowledge and understanding. Thorium reprocessing and waste management are poorly understood. The thorium fuel cycle cannot be considered to be mature in any area."

Fiona Rayment from the UK National Nuclear Laboratory states:[486]
"It is conceivable that thorium could be introduced in current generation reactors within about 15 years, if there was a clear economic benefit to utilities. This would be a once-through fuel cycle that would partly realise the strategic benefits of thorium.
"To obtain the full strategic benefit of the thorium fuel cycle would require recycle, for which the technological development timescale is longer, probably 25 to 30 years.

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[483] Tim Dean, 16 March 2011, 'The greener nuclear alternative', https://www.abc.net.au/news/2011-03-16/thoriumdean/45178
[484] www.world-nuclear.org/info/Current-and-Future-Generation/Thorium/
[485] UK National Nuclear Laboratory Ltd., 5 March 2012, 'Comparison of thorium and uranium fuel cycles', www.decc.gov.uk/assets/decc/11/meeting-energy-demand/nuclear/6300-comparison-fuel-cycles.pdf
[486] Stephen Harris, 9 Jan 2014, 'Your questions answered: thorium-powered nuclear', www.theengineer.co.uk/energy-and-environment/in-depth/your-questions-answered-thorium-powered-nuclear/1017776.article

"To develop radical new reactor designs, specifically designed around thorium, would take at least 30 years. It will therefore be some time before the thorium fuel cycle can realistically be expected to make a significant contribution to emissions reductions targets."

Kirk Sorensen, founder of a US firm which aims to build a demonstration 'liquid fluoride thorium reactor' (a type of molten salt reactor − MSR), notes that "several technical hurdles" confront thorium-fuelled MSRs, including materials corrosion, reactor control and in-line processing of the fuel.[487]

Nuclear physicist Prof. George Dracoulis writes:[488]
"MSRs are not currently available at an industrial scale, but test reactors with different configurations have operated for extended periods in the past. But there are a number of technical challenges that have been encountered along the way. One such challenge is that the hot beryllium and lithium "salts" – in which the fuel and heavy wastes are dissolved – are highly reactive and corrosive. Building a large-scale system that can operate reliably for decades is non-trivial. That said, many of the components have been the subject of extensive research programs."

The 2015 report[489] by the French government's Institute for Radiological Protection and Nuclear Safety states that for molten salt reactors (MSR) and SuperCritical Water Reactors (SCWR) systems, there "is no likelihood of even an experimental or prototype MSR or SCWR being built during the first half of this century" and "it seems hard to imagine any reactor being built before the end of the century".

Thorium is no 'silver bullet'

Do thorium reactors potentially offer significant advantages compared to conventional uranium reactors?

Prof. George Dracoulis states: "Some of the rhetoric associated with thorium gives the impression that thorium is, somehow, magical. In reality it isn't."[490]

The UK National Nuclear Laboratory report argues that thorium has "theoretical advantages regarding sustainability, reducing radiotoxicity and reducing proliferation risk" but that "while there is some justification for these benefits, they are often over stated."[491] The report further states that the purported benefits "have yet to be demonstrated or substantiated, particularly in a commercial or regulatory environment." The report further states: "Thorium fuelled reactors have already been advocated as being inherently safer than LWRs [light water reactors], but the basis of these claims is not sufficiently substantiated and will not be for many years, if at all."

[487] Stephen Harris, 9 Jan 2014, 'Your questions answered: thorium-powered nuclear', www.theengineer.co.uk/energy-and-environment/in-depth/your-questions-answered-thorium-powered-nuclear/1017776.article

[488] George Dracoulis, 19 Dec 2011, 'Thoughts from a thorium 'symposium'', http://theconversation.com/thoughts-from-a-thorium-symposium-4545

[489] Institute for Radiological Protection and Nuclear Safety, 2015, 'Review of Generation IV Nuclear Energy Systems', www.irsn.fr/EN/newsroom/News/Pages/20150427_Generation-IV-nuclear-energy-systems-safety-potential-overview.aspx Direct download: www.irsn.fr/EN/newsroom/News/Documents/IRSN_Report-GenIV_04-2015.pdf

[490] George Dracoulis, 5 Aug 2011, 'Thorium is no silver bullet when it comes to nuclear energy, but it could play a role', http://theconversation.com/thorium-is-no-silver-bullet-when-it-comes-to-nuclear-energy-but-it-could-play-a-role-1842

[491] UK National Nuclear Laboratory Ltd., 5 March 2012, 'Comparison of thorium and uranium fuel cycles', www.decc.gov.uk/assets/decc/11/meeting-energy-demand/nuclear/6300-comparison-fuel-cycles.pdf

Thorium and proliferation

Claims that thorium reactors would be proliferation-resistant or proliferation-proof do not stand up to scrutiny.[492] Irradiation of thorium-232 produces uranium-233, which can be and has been used in nuclear weapons.

The World Nuclear Association states:[493]
"The USA produced about 2 tonnes of U-233 from thorium during the 'Cold War', at various levels of chemical and isotopic purity, in plutonium production reactors. It is possible to use U-233 in a nuclear weapon, and in 1955 the USA detonated a device with a plutonium-U-233 composite pit, in Operation Teapot. The explosive yield was less than anticipated, at 22 kilotons. In 1998 India detonated a very small device based on U-233 called Shakti V."

According to Assoc. Prof. Nigel Marks, both the US and the USSR tested uranium-233 bombs in 1955.[494]

Uranium-233 is contaminated with uranium-232 but there are ways around that problem. Kang and von Hippel note:[495]
"[J]ust as it is possible to produce weapon-grade plutonium in low-burnup fuel, it is also practical to use heavy-water reactors to produce U-233 containing only a few ppm of U-232 if the thorium is segregated in "target" channels and discharged a few times more frequently than the natural-uranium "driver" fuel."

John Carlson, former Director-General of the Australian Safeguards and Non-proliferation Office, discusses the proliferation risks associated with thorium:[496]

"The thorium fuel cycle has similarities to the fast neutron fuel cycle – it depends on breeding fissile material (U-233) in the reactor, and reprocessing to recover this fissile material for recycle. ...
"Proponents argue that the thorium fuel cycle is proliferation resistant because it does not produce plutonium. Proponents claim that it is not practicable to use U-233 for nuclear weapons.
"There is no doubt that use of U-233 for nuclear weapons would present significant technical difficulties, due to the high gamma radiation and heat output arising from decay of U-232 which is unavoidably produced with U-233. Heat levels would become excessive within a few weeks, degrading the high explosive and electronic components of a weapon and making use of U-233 impracticable for stockpiled weapons. However, it would be possible to develop strategies to deal with these drawbacks, e.g. designing weapons where the fissile "pit" (the core of the nuclear weapon) is not inserted until required, and where ongoing production and treatment of U-233 allows for pits to be continually replaced. This might not be practical for a large arsenal, but could certainly be done on a small scale.
"In addition, there are other considerations. A thorium reactor requires initial core fuel – LEU or plutonium – until it reaches the point where it is producing sufficient U-233 for self-sustainability, so the cycle is not entirely free of issues applying to the uranium fuel cycle (i.e. requirement for enrichment or

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492 'Thor-bores and uro-sceptics: thorium's friendly fire', Nuclear Monitor #801, 9 April 2015, https://www.wiseinternational.org/nuclear-monitor/801/thor-bores-and-uro-sceptics-thoriums-friendly-fire

493 www.world-nuclear.org/info/Current-and-Future-Generation/Thorium/

494 Nigel Marks, 2 March 2015, 'Should Australia consider thorium nuclear power?', http://theconversation.com/should-australia-consider-thorium-nuclear-power-37850

495 Jungmin Kang and Frank N. von Hippel, 2001, "U-232 and the Proliferation-Resistance of U-233 in Spent Fuel", *Science & Global Security*, Volume 9, pp.1-32, www.princeton.edu/sgs/publications/sgs/pdf/9_1kang.pdf

496 John Carlson, 2009, 'Introduction to the Concept of Proliferation Resistance', www.foe.org.au/sites/default/files/Carlson%20ASNO%20ICNND%20Prolif%20Resistance.doc or http://archive.foe.org.au/sites/default/files/Carlson%20ASNO%20ICNND%20Prolif%20Resistance.doc

reprocessing). Further, while the thorium cycle can be self-sustaining on produced U-233, it is much more efficient if the U-233 is supplemented by additional "driver" fuel, such as LEU or plutonium. For example, India, which has spent some decades developing a comprehensive thorium fuel cycle concept, is proposing production of weapons grade plutonium in fast breeder reactors specifically for use as driver fuel for thorium reactors. This approach has obvious problems in terms of proliferation and terrorism risks.

"A concept for a liquid fuel thorium reactor is under consideration (in which the thorium/uranium fuel would be dissolved in molten fluoride salts), which would avoid the need for reprocessing to separate U-233. If it proceeds, this concept would have non-proliferation advantages.

"Finally, it cannot be excluded that a thorium reactor – as in the case of other reactors – could be used for plutonium production through irradiation of uranium targets.

"Arguments that the thorium fuel cycle is inherently proliferation resistant are overstated. In some circumstances the thorium cycle could involve significant proliferation risks."

False distinctions between thorium and uranium

Some thorium advocates posit a sharp distinction between thorium and uranium. But there is little to distinguish the two. A much more important distinction is between conventional reactor technology and some 'Generation IV' concepts − in particular, those based on repeated (or continuous) fuel recycling and the 'breeding' of fissile isotopes from fertile isotopes (Thorium-232>Uranium-233 or Uranium-238>Plutonium-239).

A report by the Idaho National Laboratory states:[497]

"For fuel type, either uranium-based or thorium-based, it is only in the case of continuous recycle where these two fuel types exhibit different characteristics, and it is important to emphasize that this difference only exists for a fissile breeder strategy. The comparison between the thorium/U-233 and uranium/Pu-239 option shows that the thorium option would have lower, but probably not significantly lower, TRU [transuranic waste] inventory and disposal requirements, both having essentially equivalent proliferation risks.

"For these reasons, the choice between uranium-based fuel and thorium-based fuels is seen basically as one of preference, with no fundamental difference in addressing the nuclear power issues.

"Since no infrastructure currently exists in the U.S. for thorium-based fuels, and processing of thorium-based fuels is at a lower level of technical maturity when compared to processing of uranium-based fuels, costs and RD&D requirements for using thorium are anticipated to be higher."[498]

Prof. George Dracoulis takes issue with the "particularly silly claim" by a science journalist (and others) that almost all the thorium is usable as fuel compared to just 0.7% of uranium (i.e. uranium-235), and that thorium can therefore power civilization for millennia. Prof. Dracoulis states:[499]

"In fact, in that sense, none of the thorium is usable since it is not fissile. The comparison should be with the analogous fertile isotope uranium-238, which makes up nearly 100% of natural uranium. If you wanted to go that way (breeding that is), there is already enough uranium-238 to 'power civilization for millennia'."

[497] Idaho National Laboratory, Sept 2009, 'AFCI Options Study', INL/EXT-10-17639, https://www.researchgate.net/publication/255214351_AFCI_Options_Study or https://inldigitallibrary.inl.gov/sites/sti/sti/4480296.pdf

[498] Ibid.

[499] George Dracoulis, 5 Aug 2011, 'Thorium is no silver bullet when it comes to nuclear energy, but it could play a role', http://theconversation.com/thorium-is-no-silver-bullet-when-it-comes-to-nuclear-energy-but-it-could-play-a-role-1842

Some Generation IV concepts promise major advantages, such as the potential to use long-lived nuclear waste and weapons-usable material (esp. plutonium) as reactor fuel using breeding and continuous recycling. But those concepts are generally those that face the greatest technical challenges. Moreover, uranium/plutonium fast reactor technology might more accurately be described as failed Generation I technology: the history of fast reactors has largely been one of extremely expensive, underperforming and accident-prone reactors which have contributed more to WMD proliferation problems than to the resolution of those problems.[500]

Most importantly, whether Generation IV concepts deliver on their potential depends on a myriad of factors − not just the resolution of technical challenges. India's fast reactor / thorium program illustrates how badly things can go wrong, and it illustrates problems that can't be solved with technical innovation. John Carlson writes:
"India has a plan to produce [weapons-grade] plutonium in fast breeder reactors for use as driver fuel in thorium reactors. This is problematic on non-proliferation and nuclear security grounds. Pakistan believes the real purpose of the fast breeder program is to produce plutonium for weapons (so this plan raises tensions between the two countries); and transport and use of weapons-grade plutonium in civil reactors presents a serious terrorism risk (weapons-grade material would be a priority target for seizure by terrorists)."[501]

Generation IV thorium concepts such as molten salt reactors (MSR) have a lengthy, uncertain R&D road ahead of them − notwithstanding the fact that there is some previous R&D to build upon.[502] Kirk Sorensen, founder of a US firm which aims to build a demonstration 'liquid fluoride thorium reactor' (a type of MSR), notes that "several technical hurdles" confront thorium-fuelled MSRs, including materials corrosion, reactor control and in-line processing of the fuel.[503]

Prof. George Dracoulis writes:[504]
"MSRs are not currently available at an industrial scale, but test reactors with different configurations have operated for extended periods in the past. But there are a number of technical challenges that have been encountered along the way. One such challenge is that the hot beryllium and lithium "salts" – in which the fuel and heavy wastes are dissolved – are highly reactive and corrosive. Building a large-scale system that can operate reliably for decades is non-trivial. That said, many of the components have been the subject of extensive research programs."

Further information on thorium

The following report provides useful information:
Dr. Rainer Moormann, 2018, 'Thorium – a better fuel for nuclear technology?', Nuclear Monitor #858, https://www.wiseinternational.org/nuclear-monitor/858/thorium-%E2%80%92-better-fuel-nuclear-technology

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[500] 'The slow death of fast reactors', 2 Nov 2016, https://energypost.eu/slow-death-fast-reactors/
[501] John Carlson, 2014, submission to Joint Standing Committee on Treaties, Parliament of Australia, www.aph.gov.au/DocumentStore.ashx?id=79a1a29e-5691-4299-8923-06e633780d4b&subId=301365
[502] Stephen Harris, 9 Jan 2014, 'Your questions answered: thorium-powered nuclear', www.theengineer.co.uk/energy-and-environment/in-depth/your-questions-answered-thorium-powered-nuclear/1017776.article
See also: Oliver Tickell, August/September 2012, 'Thorium: Not 'green', not 'viable', and not likely', www.no2nuclearpower.org.uk/nuclearnews/NuClearNewsNo43.pdf
[503] Stephen Harris, 9 Jan 2014, 'Your questions answered: thorium-powered nuclear', The Engineer (UK). Article available from jim.green@foe.org.au
[504] George Dracoulis, 19 Dec 2011, 'Thoughts from a thorium 'symposium'', http://theconversation.com/thoughts-from-a-thorium-symposium-4545

APPENDIX 6: HIGH-TEMPERATURE GAS-COOLED ZOMBIE REACTORS

High-temperature gas-cooled reactors (HTGRs) and their pebble-bed modular reactor (PBMR) sub-type have a long and troubled history. But the zombie HTGR concept refuses to die: each failure is followed by another attempt and another failure.

Here is an excerpt from a 2010 report on the failure of South Africa's PBMR project:[505]
"The Pebble Bed Modular Reactor. Remember? It was globally heralded as the perfect nuclear reactor: small, safe and cheap. Dozens would be built in South Africa alone and in 1999 the company expected to sell 30 reactors annually from 2004 on.
"Now, the South African government announced it is expected to close operations at PBMR (Pty) Ltd. finally 'within a few weeks' (that is August). The company once planned to build up to 24 165-MW high-temperature gas-cooled reactor modules for state-owned utility Eskom and export the modular HTR worldwide, but hasn't built even the demonstration model.
"The government has invested an estimated South Africa Rand 9 billion (US$1.23 billion at current rates) in PBMR Ltd. over the 11 years since it was founded as an Eskom subsidiary. PBMR Ltd. is formally owned by Eskom, the Industrial Development Corp. and Westinghouse, but they have put no equity in the company for several years.
"In a July statement, the Department of Public Enterprises, which has responsibility for the PBMR company, said PBMR "has not been able to acquire additional investment in the project since government's last funding allocation in 2007, nor has it been able to acquire an anchor customer despite revising its business model in 2008/09."
"The company is operating on funds that were left over from the 2007 allocation and has downsized from about 800 staff to about 25. Although the PBMR website doesn't show anything about the current situation, it says there are "no career opportunities at the moment."
"The company was set up in 1999 as Pebble Bed Modular Reactor (Pty) Ltd. to develop and deploy German technology it had acquired for small HTRs with coated pebble-shaped fuel elements. Besides British Nuclear Fuels plc (BNFL), Exelon, the largest nuclear fleet operator in the US, also made an early equity investment, and the company was broadly touted as the herald of a new nuclear age for the developing world based on small reactors that could be set up quickly under various site conditions. BNFL's stake was transferred to Westinghouse when the latter was sold to Toshiba.
"But the PBMR partners never agreed on a new equity structure and the company remained the property of the South African government. The Department of Public Enterprises believes the R9-billion spent on the PBMR project has not been lost, as the skills developed "will contribute significantly in any future nuclear programs and save the country huge amounts of money in the process".
"One of the critics, Stephen Thomas, professor of energy policy at the University of Greenwich in the UK, told the Cape Times that it was clear at least six years ago that the PBMR project was "going badly wrong. Yet the government continued to pour public money into it, indeed about 80 percent of all the money spent on the pebble bed was spent in the past six years.
"Tristen Taylor, of Earthlife Africa, said "We hope that this will also mark the end of the South African government's love affair with nuclear energy and that taxpayer funds can now be spent on clean, proven and reliable forms of renewable energy"."

The demise of PBMRs ... and China's attempted revival

Steve Thomas, Professor of Energy Policy at the University of Greenwich, wrote about the demise of PBMRs in the *Bulletin of the Atomic Scientists* in 2009.[506] Prof. Thomas covered the failure of PBMR

[505] Nuclear Monitor #714, 20 Aug 2010, 'The end is near for the PBMR', https://www.wiseinternational.org/nuclear-monitor/714/end-near-pbmr

projects in Germany and South Africa. He noted that the cost of the proposed PBMR demonstration plant in South Africa was initially US$223 million but the estimate had escalated eight-fold to at least US$1.8 billion by the time the project was abandoned.

Prof. Thomas concluded:[507]
"All the major countries involved in designing reactors, including the United States, Germany, France, Japan, and Britain, have put major time and effort into developing high-temperature, gas-cooled reactors such as the PBMR. Despite more than 50 years of trying, however, no commercial-scale design has yet been produced. Yet China and South Africa have found the allure of pebble bed technology irresistible, as if it were an "unpolished gem" waiting to be developed, regardless of the consistent engineering problems it has had since the beginning.
"South Africa took a particularly aggressive approach, believing that it could develop a commercial-size PBMR design without even operating a prototype. If the PBMR is proved to be fundamentally flawed, as indicated in the Jülich report[3], South Africa's $980 million investment in the project will be seen in hindsight as wasteful, one that the country, plagued with many more pressing and basic problems, could ill afford."

The Jülich report mentioned by Thomas is the Jülich Center's 2008 review of its previous PBMR work.[508] It was Jülich's design – specifically the prototype PBMR – which South Africa had taken as the basis for its PBMR. It seems that one after another nuclear nation is destined to find out for themselves that HTGR/PBMR designs are technically challenging and are best avoided.

China is building one demonstration HTGR/PBMR: twin reactors driving a single 210 MWe turbine.[509] Further HTGR feasibility studies are underway in China[510] but plans for 18 additional HTGR/PBMRs (with total capacity of 3,800 MW) at the same site as the demonstration plant have been "dropped" according to the World Nuclear Association.[511] In 2016, completion of the demonstration reactor was anticipated the following year, and China's HTGRs would be on the world market within five years.[512] But the demonstration reactor has not been completed as of September 2019. Construction cost estimates of the demonstration HTGR have approximately doubled.[513]

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[506] Steve Thomas, 22 June 2009, 'The demise of the pebble bed modular reactor', http://thebulletin.org/demise-pebble-bed-modular-reactor
[507] ibid.
[508] R. Moormann, "A Safety Re-evaluation of the AVR Pebble Bed Reactor Operation and Its Consequences for Future HTR Concepts," Forschungszentrum Jülich, 2008, https://inis.iaea.org/collection/NCLCollectionStore/_Public/39/099/39099096.pdf?r=1&r=1
[509] World Nuclear Association, 21 March 2016, 'First vessel installed in China's HTR-PM unit', http://www.world-nuclear-news.org/NN-First-vessel-installed-in-Chinas-HTR-PM-unit-2103164.html
[510] World Nuclear Association, 19 Sept 2017, 'China plans further high temperature reactor innovation', http://www.world-nuclear-news.org/NN-China-plans-further-high-temperature-reactor-innovation-1909171.html
[511] World Nuclear Association, 21 March 2016, 'First vessel installed in China's HTR-PM unit', http://www.world-nuclear-news.org/NN-First-vessel-installed-in-Chinas-HTR-PM-unit-2103164.html
[512] Dan Yurman, 13 Feb 2016, 'Nuclear News Roundup for 2/14/16', http://neutronbytes.com/2016/02/13/nuclear-news-roundup-for-21416/
See also: Richard Martin, 11 Feb 2016, 'Two high-temperature, gas-cooled reactors under construction in Shandong will make up the first commercial-scale plant of its type in the world', https://www.technologyreview.com/s/600757/china-could-have-a-meltdown-proof-nuclear-reactor-next-year/
[513] 1 Dec 2016, 'China's plans to begin converting coal plants to walk away safe pebble bed nuclear starting in the 2020s', http://www.nextbigfuture.com/2016/12/chinas-plans-to-begin-converting-coal.html

The checkered history of HTGRs

University of British Columbia academic M.V. Ramana has written a summary of the troubled history of HTGR / PBMR projects.[514] An excerpt from Ramana's article is reproduced here:

"Proponents of HTGRs often claim that their designs have a long pedigree. ... But if one examines that very same experience more closely – looking in particular at the HTGRs that were constructed in Western Europe and the United States to feed power into the electric grid – then one comes to other conclusions. This history suggests that while HTGRs may look attractive on paper, their performance leaves much to be desired. The technology may be something that looks better on paper than in the real world ...

"Although Germany abandoned this technology, it did migrate to other countries, including China and South Africa. Of these, the latter case is instructive: South Africa pursued the construction of a pebble-bed reactor for a decade, and spent over a billion dollars, only to abandon it in 2009 because it just did not make sense economically. Although sold by its proponents as innovative and economically competitive until its cancellation, the South African pebble-bed reactor project is now being cited as a case study in failure. How good the Chinese experience with the HTGR will be remains to be seen. ...

"From these experiences in operating HTGRs, we can take away several lessons – the most important being that HTGRs are prone to a wide variety of small failures, including graphite dust accumulation, ingress of water or oil, and fuel failures. Some of these could be the trigger for larger failures or accidents, with more severe consequences. ... Other problems could make the consequences of a severe accident worse: For example, pebble compaction and breakage could lead to accelerated diffusion of fission products such as radioactive cesium and strontium outside the pebbles, and a potentially larger radioactive release in the event of a severe accident. ...

"Discussions of the commercial viability of HTGRs almost invariably focus on the expected higher capital costs per unit of generation capacity (dollars per kilowatts) in comparison with light water reactors, and potential ways for lowering those. In other words, the main challenge they foresee is that of building these reactors cheaply enough. But what they implicitly or explicitly assume is that HTGRs would operate as well as current light water reactors – which is simply not the case, if history is any guide. ...

"Although there has been much positive promotional hype associated with high-temperature reactors, the decades of experience that researchers have acquired in operating HTGRs has seldom been considered. Press releases from the many companies developing or selling HTGRs or project plans in countries seeking to purchase or construct HTGRs neither tell you that not a single HTGR-termed "commercial" has proven financially viable nor do they mention that all the HTGRs were shut down well before the operating periods envisioned for them. This is typical of the nuclear industry, which practices selective remembrance, choosing to forget or underplay earlier failures."

[514] M. V. Ramana, April 2016, 'The checkered operational history of high-temperature gas-cooled reactors', Bulletin of the Atomic Scientists, http://dx.doi.org/10.1080/00963402.2016.1170395