SUBMISSION TO JOINT STANDING COMMITTEE ON TREATIES

on the Agreement Extending the Framework Agreement for International Collaboration on Research and Development of Generation IV Nuclear Energy Systems

by Friends of the Earth Australia and the Australian Conservation Foundation

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1. INTRODUCTION AND RESPONSE TO NATIONAL INTEREST ANALYSIS

Friends of the Earth Australia and the Australian Conservation Foundation welcome the opportunity to make a submission to this inquiry and would welcome the opportunity to appear before a hearing of the Committee.

The Committee will likely receive submissions promoting the construction of Generation IV reactors in Australia and it is therefore worth noting comments by the SA Nuclear Fuel Cycle Royal Commission in its May 2016 Final Report: "[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."[1]

Here we provide brief responses to a number of comments in the National Interest Analysis (NIA).[2]

The NIA asserts that participation in the Generation IV International Forum (GIF) will further Australia's non-proliferation and nuclear safety objectives. No evidence is supplied to justify the 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 Australian Obligated Nuclear Materials (AONM); a reversal of the decision to permit uranium sales to countries that have not signed or ratified the NPT; or refusing uranium sales to countries that refuse to sign or ratify the Comprehensive Test Ban Treaty. There is much else that Australia could do – but is not doing – that would demonstrably further safety objectives, e.g. revisiting the decision to sell uranium to Ukraine in light of the ongoing conflict in that country, refusing to supply uranium to nuclear weapon states that are not fulfilling their NPT obligations, 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, India, Russia, Ukraine and others).

Nuclear non-proliferation would also be far better realised by active Australian engagement in the current UN process around the development of a nuclear weapons ban treaty. Instead Australia has spurned this pivotally important initiative and is refusing to participate. If Australia is serious about its international standing, our representatives would be at the table in New York.

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.

The NIA asserts that accession to the Agreement and participation in GIF will have important economic benefits. No evidence is supplied to justify that tenuous assertion. There are no demonstrated economic benefits from participation in GIF – however there are clear costs.

The NIA states that the "costs of participation in the System Arrangements will be borne by ANSTO from existing funds." ANSTO should be required to provide a detailed account of past expenditure relating to this Agreement and anticipated future expenditure.

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 on nuclear issues." Those arguments are tenuous, especially given that little about GIF is secret.

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 claims are rebuked in later sections of this submission.

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[1] http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf

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

The NIA states that the success of Australia's bid for membership of GIF was based in part on ANSTO's "world-class capabilities and expertise" in the "development of nuclear safety cases." ANSTO should be asked to justify that assertion. ANSTO could also be asked whether, based on its "world-class" expertise in nuclear safety, whether it considers it is appropriate for Australia to sell uranium to countries with demonstrably inadequate nuclear regulatory regimes, e.g. China, India, Russia, Ukraine and others.

The NIA asserts that "a significant expansion in nuclear power production is underway or under consideration by a number of countries, including several in the Asia Pacific region." In fact:

- Globally, nuclear power has been stagnant for the past 20 years.
- For the foreseeable future, there is zero likelihood of a "significant" nuclear expansion of nuclear power and there will be an overall decline unless growth in China matches the decline elsewhere. Declines can be predicted with great confidence in North America, across all EU countries combined, in Japan, and in numerous other countries and regions – and a very large majority of the world's countries (about five out of six) are nuclear-free and plan to stay that way.
- No country in the Asia Pacific or South East Asia is seriously planning to introduce nuclear power. The only country that was seriously planning to introduce nuclear power in the region – Vietnam – abandoned those plans last year.

The NIA states that Australia's participation in GIF falls within the existing functions of ANSTO under Section 5 of the *Australian Nuclear Science and Technology Organisation Act* 1987. The Joint Standing Committee on Treaties should assess whether Australia's participation in GIF is consistent with legislation banning nuclear power in Australia (the EPBC and ARPANS Acts).

2. GENERATION IV REACTOR CONCEPTS – INTRODUCTION

So-called 'next generation' or 'Generation IV' reactor concepts are diverse. Some are far from new − in particular, variations of fast (a.k.a. fast spectrum or fast neutron) reactor technology have existed for decades and have a troubled history.

The politicking around Generation IV technology promotion is summarised by British environmentalist and author Jonathon Porritt:[3]

> *"[T]he nuclear industry is now increasingly active in talking up the prospects for Generation IV reactor designs, which will (we are told) address all the same problems that Generation III designs were supposed to address. Right now, for instance, there's an outspoken lobby making the case for Small Modular Reactors – an idea which is readily badged as Generation IV but actually goes back to the 1960s. Then the 1980s. Then the 1990s. Then the early 2000s! As the International Energy Agency commented in 2002, in an era when it was rather more bullish about nuclear power:* "The main reason for this stalemate is that we, in all our doings, continue to rely on nuclear technology developed in the 1950s, which had its roots in military applications which cannot exclude absolutely the possibility of a severe accident and which has reached its limits from an economic point of view."
> *"For those who've now somewhat given up on Small Modular Reactors and other so-called "advanced nuclear reactors", there's always the promise of an entirely new nuclear value chain based not on uranium but on thorium – another proposition that has been around for more than 50 years. And what's remarkable here is that even the keenest advocates of*

[3] Foreword in Mycle Schneider, Antony Froggatt et al., July 2015, 'World Nuclear Industry Status Report 2015', www.worldnuclearreport.org/-2015-.html

thorium acknowledge that it couldn't possibly make a substantive, cost-effective contribution to the world's need for low-carbon energy for at least another 20 years.
"The consistent history of innovation in the nuclear industry is one of periodic spasms of enthusiasm for putative breakthrough technologies, leading to the commitment of untold billions of investment dollars, followed by a slow, unfolding story of disappointment caused by intractable design and cost issues. ***Purely from an innovation perspective, it's hard to imagine a sorrier, costlier and more self-indulgent story of serial failure."*** *(emphasis added)*

3. DECADES AWAY

It is generally understood – even by most Generation IV advocates – that the development and in particular the commercialisation of Generation IV technology is decades away. Such statements miss the point that the development and commercialisation of Generation IV technology has *always* been decades away. Decades from now, the development and commercialisation of Generation IV technology will probably still be decades away. Reasons for this include:

- Some Generation IV concepts (e.g. fast reactors) are best described as failed Generation I technology.
- Purported benefits of Generation IV concepts do not stand up to scrutiny and are unlikely to be realised.
- There is little likelihood that Generation IV will resolve the high costs of nuclear power, in particular the extraordinary construction costs and attendant problems such as the multi-billion-dollar costs overruns that have bankrupted industry giant Westinghouse, may yet bankrupt its parent company Toshiba, and would have bankrupted French utilities EDF and Areva if not for repeated multi-billion-dollar taxpayer bailouts.

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."[4]

A 2015 report by the French government's Institute for Radiological Protection and Nuclear Safety (IRSN) 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."[5]

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."[6]

The SA Nuclear Fuel Cycle Royal Commission noted in its May 2016 Final Report:[7]
"The recent conclusion of the Generation IV International Forum (GIF), which issued updated projections for fast reactor and innovative systems in January 2014, suggests the most advanced system will start a demonstration phase (which involves completing the detailed design of a prototype system and undertaking its licensing, construction and operation) in about 2021.

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[4] 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
[5] 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
[6] World Nuclear Association, 15 Dec 2009, 'Fast moves? Not exactly...', www.world-nuclear-news.org/NN_France_puts_into_future_nuclear_1512091.html
[7] http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf

"The demonstration phase is expected to last at least 10 years and each system demonstrated will require funding of several billion US dollars. As a result, the earliest possible date for the commercial operation of fast reactor and other innovative reactor designs is 2031. This timeframe is subject to significant project, technical and funding risk.
"It extends by six years a similar assessment undertaken by GIF in 2002. This means that such designs could not realistically be ready for commercial deployment in South Australia or elsewhere before the late 2030s, and possibly later."

The six Generation IV concepts being investigated by the Generation IV International Forum are: the gas-cooled fast reactor, the sodium-cooled fast reactor, the lead-cooled fast reactor, the molten salt reactor, the supercritical water-cooled reactor, and the very high temperature reactor.[8] 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."[9]

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."[10]

In January 2014, the Generation IV International Forum released its 'Technology Roadmap Update for Generation IV Nuclear Energy Systems'. It updates the GIF 2002 Technology Roadmap.[11] The GIF measures progress according to three (pre-commercialisation) phases:

- the viability phase, when basic concepts are tested under relevant conditions and all potential technical show-stoppers are identified and resolved;
- the performance phase, when engineering-scale processes, phenomena and materials capabilities are verified and optimised under prototypical conditions; and
- the demonstration phase, when detailed design is completed and licensing, construction and operation of the system are carried out, with the aim of bringing it to the commercial deployment stage.

The projections made in the 2002 Technology Roadmap were revised as follows in 2014:

- *Gas-cooled fast reactor*: end of viability phase pushed back from 2012 to 2022; end of performance phase pushed back from 2020 to 2030.
- *Molten salt reactor*: end of viability phase pushed back from 2013 to 2025; end of performance phase pushed back from 2020 to 2030.
- *Sodium-cooled fast reactor*: end of viability phase pushed back from 2006 to 2012; end of performance phase pushed back from 2015 to 2022.
- *Supercritical-water-cooled reactor*: end of viability phase pushed back from 2014 to 2015; end of performance phase pushed back from 2020 to 2025.
- *Very-high-temperature reactor*: end of viability phase remains at 2010; end of performance phase pushed back from 2015 to 2025.
- *Lead-cooled fast reactor*: end of viability phase brought forward from 2014 to 2013; end of performance phase pushed back from 2020 to 2021.

[8] www.gen-4.org/gif/jcms/c_40465/generation-iv-systems
[9] www.gen-4.org/gif/jcms/c_9260/public
[10] www.gen-4.org/gif/jcms/c_41890/faq-2
[11] www.gen-4.org/gif/jcms/c_60729/technology-roadmap-update-2013

Averaging across the six reactor concepts: the end of the viability phase was pushed back by an average of 4.7 years, and the end of the performance phase pushed back by an average of 7.2 years. That is a lot of slippage in the 11 years since the 2002 Technology Roadmap − all the more so since the latest projections may prove to be as optimistic as those in the 2002 report. Demonstration phases and commercial phases are a very long way away.

4. PURPORTED BENEFITS

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

The French government's Institute for Radiological Protection and Nuclear Safety reviewed the six concepts prioritised by the Generation IV International Forum and concluded: "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] ..." [12]

Moreover the VHTR system could bring about significant safety improvements, the Institute for Radiological Protection and Nuclear Safety states, "but only by significantly limiting unit power".[13]

Regarding Generation IV concepts, Hirsch et al. state:
"A closer look at the technical concepts shows that many safety problems are still completely unresolved. Safety improvements in one respect sometimes create new safety problems. And even the Generation IV strategists themselves do not expect significant improvements regarding proliferation resistance. But even real technical improvements that might be feasible in principle are only implemented if their costs are not too high. There is an enormous discrepancy between the catch-words used to describe Generation IV for the media, politicians and the public, and the actual basic driving force behind the initiative, which is economic competitiveness."[14]

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 and most of the countries that invested in fast reactor technology have since abandoned those efforts.

The history of fast reactors has largely been one of extremely expensive, underperforming and accident-prone reactors. They have contributed to WMD proliferation but not to the resolution of the nuclear proliferation problem, despite the claims of fast reactor advocates. France has used a fast reactor to produce plutonium for weapons and India plans to do the same in the coming years.

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[12] 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

[13] 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

[14] 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, www.greenpeace.org/international/press/reports/nuclearreactorhazards

The troubled history of fast reactors is detailed in a report by the International Panel on Fissile Materials[15] and is further discussed later in this submission.

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:
"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)."[16]

5. FRENCH GOVERNMENT'S IRSN REPORT

A 2015 report[17] by the French government's Institute for Radiological Protection and Nuclear Safety (IRSN) is of particular significance, coming from a government which has invested heavily in nuclear technology including Generation IV R&D. IRSN is a government authority with 1,790 staff under the joint authority of the Ministries of Defense, Environment, Industry, Research, and Health.

The IRSN report focuses on the six Generation IV concepts prioritised by the Generation IV International Forum (GIF), which brings together 12 countries with an interest in new reactor types, plus Euratom. France is itself one of the countries involved in the GIF.

The 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."

IRSN considers the sodium-cooled fast reactor (SFR) system to be the only one to have reached a degree of maturity compatible with the construction of a reactor prototype during the first half of this century − and even the development of an SFR prototype would require further preliminary studies and technological developments.

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

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[15] International Panel on Fissile Materials, Feb 2010, 'Fast Breeder Reactor Programs: History and Status', www.ipfmlibrary.org/rr08.pdf
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

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

[17] 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

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".

IRSN notes that it is difficult to thoroughly evaluate safety and radiation protection standards of Generation IV systems as some concepts have already been partially tried and tested, while others are still in the early stages of development.

The report 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." It notes that ASN, the French nuclear safety authority, has recently announced that minor actinide transmutation would not be a deciding factor in the choice of a future reactor system.

The IRSN's findings on the six GIF concepts are briefly summarised here:

Sodium-cooled Fast Reactors (SFR)

- The main safety advantage is the use of low-pressure liquid coolant. The normal operating temperature of this coolant is significantly lower than its boiling point, allowing a grace period of several hours during loss-of-cooling events. The advantage gained from the high boiling point of sodium, however, must be weighed against the fact that the structural integrity of the reactor cannot be guaranteed near this temperature.
- The use of sodium also comes with a number of drawbacks due to its high reactivity not only with water and air, but also with MOX fuel.
- It seems possible for SFR technology to reach a safety level at least equivalent to that of Generation III pressurised water reactors, but IRSN is unable to determine whether it could significantly exceed this level, in view of design differences and the current state of knowledge and research.

Very High Temperature Reactors (VHTR)

- The VHTR benefits from the operating experience feedback obtained from High Temperature Reactors (HTR).
- This technology is intrinsically safe with respect to loss of cooling, which means that it could be used to design a reactor that does not require an active decay heat removal system. The VHTR system could therefore bring about significant safety improvements compared with Generation III reactors, especially regarding core melt prevention.
- VHTR safety performance can only be guaranteed by significantly limiting unit power.
- The feasibility of the system has yet to be determined and will chiefly depend on the development of fuels and materials capable of withstanding high temperatures; the currently considered operating temperature of around 1000°C is close to the transformation temperature of materials commonly used in the nuclear industry.

Lead-cooled Fast Reactors (LFR)

- Unlike sodium, lead does not react violently with water or air.
- The thermal inertia associated with the large volume of lead used and its very high density results in long grace periods in the event of loss of cooling.
- In addition, the high boiling point at atmospheric pressure is a guarantee of high margins under normal operating conditions and rules out the risk of coolant boiling.
- The main drawback of lead-cooled (or lead-bismuth cooled) reactors is that the coolant tends to corrode and erode stainless steel structures.

- LFR safety is reliant on operating procedures, which does not seem desirable in a Generation IV reactor.
- The highly toxic nature of lead and its related products, especially polonium-210, produced when lead-bismuth is used, raises the problem of potential environmental impact.
- IRSN is unable to determine whether the LFR system could guarantee a significantly higher safety level than Generation III reactors.
- Various technical hurdles need to be overcome before a reactor of this type could be considered.

Gas-cooled Fast Reactors (GFR)

- Given the current state of GFR development, construction of an industrial prototype reactor would not be technically feasible. GFR specifications are highly ambitious and raise a number of technological problems that are still a long way from being solved.
- From the safety point of view, the GFR does not display any intrinsic quality likely to lead to a significant improvement over Generation III reactors.

Molten Salt Reactors (MSR)

- The MSR differs considerably from the other systems proposed by the GIF. The main differences are that the coolant and fuel are mixed in some models and that liquid fuel is used.
- The MSR has several advantages, including its burning, breeding and actinide-recycling capabilities.
- Its intrinsic neutron properties could be put to good use as, in theory, they should allow highly stable reactor operation. The very low thermal inertia of salt and very high operating temperatures of the system, however, call for the use of fuel salt drainage devices. System safety depends mainly on the reliability and performance of these devices.
- Salt has some drawbacks − it is corrosive and has a relatively high crystallisation temperature.
- The reactor must also be coupled to a salt processing unit and the system safety analysis must take into account the coupling of the two facilities.
- Consideration must be given to the high toxicity of some salts and substances generated by the processes used in the salt processing unit.
- The feasibility of fuel salt processing remains to be demonstrated.

Super Critical-Water-cooled Reactors (SCWR)

- The SCWR is the only system selected by GIF that uses water as a coolant. The SCWR is seen as a further development of existing water reactors and thus benefits from operating experience feedback, especially from boiling water reactors. Its chief advantage is economic.
- While the use of supercritical water avoids problems relating to the phase change from liquid to vapour, it does not present any intrinsic advantage in terms of safety.
- Thermal inertia is very low, for example, when the reactor is shut down.
- The use of supercritical water in a nuclear reactor raises many questions, in particular its behaviour under neutron flux.
- At the current stage of development, it is impossible to ascertain whether the system will eventually become significantly safer than Generation III reactors.

6. 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, which concluded:[18]

"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 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 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, produce hydrogen, or both, by the end of fiscal year 2021. However, in 2011, DoE decided not to proceed with the deployment phase of the project.

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."

The report notes the US government's generous financial support for utilities developing SMRs and advanced reactor concepts − DoE provided US$152.5 million (€137m) in fiscal year 2015 alone. Advanced reactor concepts attracting DoE largesse are the high temperature gas cooled reactor, the sodium cooled fast reactor, and to a lesser extent the molten salt reactor (specifically, a sub-type known as the fluoride salt cooled high temperature reactor).

DoE and Nuclear Regulatory Commission (NRC) officials do not expect applications for advanced reactors for at least five years. In other words, an application may (or may not) be submitted some time between five years and five centuries from now.

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[18] 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

Advanced reactor designers told the GAO that they have been challenged to find investors due to the lengthy timeframe, costs, and uncertainty. Advanced reactor concepts face greater technical challenges than light water SMRs because of fundamental design differences. Thus designers have significantly more R&D issues to resolve, including in areas such as materials studies and fuel certification, coolant chemistry studies, and safety analysis. Some members of the expert group convened by the GAO noted a potential need for new test facilities to support this work. Furthermore, according to reactor designers, certifying or licensing an advanced reactor may be particularly time-consuming and difficult, adding to the already considerable economic uncertainty for the applicants.

The process of developing and certifying a specific reactor design can take 10 years or more for design work and nearly 3.5 years, as a best case, for NRC certification. Even that timeframe is more hope than expectation. Recent light water reactor design certifications, for the Westinghouse AP1000 and the GE Hitachi ESBWR, have taken about 15 and 11 years respectively. Both the AP1000 and ESBWR are modifications of long-established reactor types, so considerably longer timeframes can be expected for advanced concepts.

The cost to develop and certify a design can range from US$1−2 billion. Developers hope that costs can be reduced as they move from certification to the construction of a first-of-a-kind plant to the construction of multiple plants. But the GAO report notes that those hopes may be unfounded: *"[S]ome studies suggest that existing, large LWRs have not greatly benefitted from industry-wide standardization or learning to date for reasons including intermittent development and production. In fact, some studies have found that "reverse or negative learning" occurs when increased complexity or operation experience leads to newer safety standards. On a related point, another reactor designer said that the cost and schedule difficulties associated with building the first new design that has been certified by the NRC and started construction in the United States in three decades − the Westinghouse AP1000, a recently designed large LWR − have made it harder for light water SMRs to obtain financing because high-profile problems have made nuclear reactors in general less attractive. ... The AP1000 was the first new design that has been certified by the NRC and started construction in the United States in three decades. However, construction problems, including supply chain and regulatory issues, have resulted in cost and schedule increases."*

7. THE SLOW DEATH OF FAST REACTORS

The Royal Commission noted in its May 2016 report that advanced fast reactors (a.k.a. fast neutron, fast breeder or fast spectrum reactors) are unlikely to be feasible or viable in the foreseeable future; that the development of such a first-of-a-kind project would have high commercial and technical risk; that there is no licensed, commercially proven design and development to that point would require substantial capital investment; and that electricity generated from such reactors has not been demonstrated to be cost competitive with current light water reactor designs.[19]

Fast neutron reactors are "poised to become mainstream" according to the World Nuclear Association.[20] But data provided by the WNA itself gives the lie to the claim. The WNA lists eight "current" fast reactors, but one of them hasn't begun operating, and another (Monju) has been permanently shut down. Currently there are six ‘operable' fast reactors (one isn't operating but

[19] Nuclear Fuel Cycle Royal Commission, Final Report, 2016, http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf

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

might in the future – hence the term ‘operable'). Here is the historical pattern based on WNA tables:[21]
1976 – 7 operable fast reactors
1986 – 11
1996 – 7
2006 – 6
2016 – 6

Worldwide, there are just three operating experimental fast reactors, one non-operating experimental fast reactor, and two larger fast reactors (both in Russia). That is a pitiful return given that more than US$100 billion (A$131 billion) has been spent on the development of fast reactor technology.[22]

The WNA lists 13 fast reactor projects under "active development" for "near- to mid-term deployment".[23] But a large majority of those 13 projects – perhaps all of them – lack both approval and funding.

One country after another has abandoned fast reactor technology. Nuclear physicist Thomas Cochran summarizes the unhappy history of fast reactors: "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."[24]

Japan's experience

The latest setback was the decision of the Japanese government in 2016 to abandon plans to restart the Monju fast breeder reactor.[25] The Japan Times reported: "Monju not only absorbed fistfuls of taxpayer money, but also suffered repeated accidents and mismanagement while only going live for a few months during its three-decade existence."[26]

Monju reached criticality in 1994 but was shut down in December 1995 after a sodium coolant leak and fire.[27] 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

[21] http://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx
[22] Thomas Cochran et al., May/June 2010, 'It's time to give up on breeder reactors', http://ipfmlibrary.org/Breeders_BAS_May_June_2010.pdf
[23] http://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx
[24] 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
[25] 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/
[26] 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/
[27] https://en.wikipedia.org/wiki/Monju_Nuclear_Power_Plant#Monju_sodium_leak_and_fire

inspections of almost 10,000 out of a total 39,000 pieces of equipment at Monju, including safety-critical equipment.

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 on 21 September 2016 that attempts to find an alternative operator have been unsuccessful.[28]

On 15 August 2016, less than a week before the extraordinary Cabinet meeting, the Nuclear Regulation Authority rejected a request to lift a ban on operating Monju, imposed in 2013 after the revelation that safety inspections of thousands of components had not been carried out.[29]

The government has already spent 1.2 trillion yen (US$12bn) on Monju.[30] The government calculated that it would cost another 600 billion yen (US$6bn) to restart Monju and keep it operating for another 10 years.[31] Offline maintenance costs amount to around 20 billion yen a year (US$200m).[32]

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 yen (US$3bn), comprising 130 billion yen to dismantle the facility, 20 billion yen to remove spent nuclear fuel, and 150 billion yen for maintenance and management costs such as electricity and labor.[33]

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.[34]

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

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[28] 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/

[29] 19 Aug 2016, 'Nuclear Regulators Keep Ban On Monju Reactor', www.japanbullet.com/news/nuclear-regulators-keep-ban-on-monju-reactor

[30] 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

[31] 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

[32] 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. See also 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/

[33] 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

[34] 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

hasn't started up. Construction has taken more than twice the expected period.[35] In July 2016, the Indian government announced yet another delay, and there is scepticism that the scheduled start-up in March 2017 will be realized. The PFBR's cost estimate has gone up by 62%.[36]

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 overly enthusiastic projections for both fast reactors and light-water reactors – and failing to meet those targets by orders of magnitude.[37]

Academic M.V. Ramana writes: "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 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."[38]

Russia's snail-paced program

Three fast reactors are in operation in Russia – BOR-60 (start-up in 1969), BN-600 (1980) and BN-800 (2014).[39] 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.[40]

The Russian government published a decree in August 2016 outlining plans to build 11 new reactors over the next 14 years. Of the 11 proposed new reactors, three are fast reactors: BREST-300 near Tomsk in Siberia, and two BN-1200 fast reactors near Ekaterinburg and Chelyabinsk, near the Ural mountains.[41] 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.[42]

As Vladimir Slivyak recently noted in *Nuclear Monitor*: "While Russian plans looks big on paper, it's unlikely that this program will be implemented. It's very likely that the current economic crisis, the deepest in history since the USSR collapsed, will axe the most of new reactors."[43]

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[35] 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
[36] Mycle Schneider, Antony Froggatt et al., 2016, World Nuclear Industry Status Report 2016, www.worldnuclearreport.org/IMG/pdf/20160713MSC-WNISR2016V2-HR.pdf
[37] 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
[38] 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
[39] World Nuclear Association, Sept 2016, 'Fast Neutron Reactors', www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx
[40] Vladimir Slivyak, December 2014, 'Russian Nuclear Industry Overview', http://earthlife.org.za/www/wp-content/uploads/2014/12/russian-nuc-ind-overview.pdf
[41] WNN, 10 Aug 2016, 'Russia to build 11 new nuclear reactors by 2030', www.world-nuclear-news.org/NP-Russia-to-build-11-new-nuclear-reactors-by-2030-10081602.html
[42] WNN, 10 Aug 2016, 'Russia to build 11 new nuclear reactors by 2030', www.world-nuclear-news.org/NP-Russia-to-build-11-new-nuclear-reactors-by-2030-10081602.html
[43] www.wiseinternational.org/nuclear-monitor/829/russia-planning-new-reactors-prospects-are-murky

While the August 2016 decree signals new interest in reviving the BN-1200 reactor project, it was indefinitely suspended in 2014, with Rosatom citing the need to improve fuel for the reactor and amid speculation about the cost-effectiveness of the project.[44]

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."[45]

Russian plans in the 1980's to construct five BN-800s in the Ural region failed to materialize and, as the International Panel on Fissile Materials noted last December, plans to scale up fast reactor deployment to 14 GW by 2030 and 34 GW by 2050 do not seem realistic.[46]

OKBM − the Rosatom subsidiary that designed the BN-1200 reactor − previously anticipated that the first BN-1200 reactor would be commissioned in 2020, followed by eight more by 2030.[47] The projection of nine BN-1200 reactors operating by 2030 was fanciful, and the latest plan for three new fast reactors by 2030 is not likely to be realized either.

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.[48]

Already there has been some backsliding from the August 2016 decree outlining plans to build 11 new reactors over the next 14 years including three fast reactors. In December 2016, Alexander Lokshin, first deputy general-director of Rosatom, said the aim is to maintain the nuclear share at around 18% of total electricity production.[24] He cited stagnant energy demand as the reason to downwardly revise nuclear plans. In January 2017, Rosatom announced that it is deferring the planned Brest-OD-300 lead-cooled fast reactor – one of the 11 new reactors trumpeted in the August 2016 decree.[25]

China's program going nowhere fast

An Australian nuclear lobbyist cites[49] the World Nuclear Association (WNA)[50] in support of his claim that the Chinese expect fast reactors "to be dominating the market by about 2030 and they'll be mass produced."

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[44] World Nuclear News, 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

[45] World Nuclear News, 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

[46] 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

[47] www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/

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

[49] https://bravenewclimate.com/2015/06/18/complaint-about-misleading-helen-caldicott-article-in-the-saturday-paper/

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

Does the WNA reference support the claim? Not at all. 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.[51] For every hour the reactor operated in 2015, it was offline for five hours, and there were three recorded reactor trips.[52]

China also has plans to build a 600 MWe 'Demonstration Fast Reactor' and then a 1,000 MWe commercial-scale fast reactor.[53] Whether the 600 MWe and 1,000 MWe reactors will be built remains uncertain – the projects have not been approved – and it would be another giant leap from a single commercial-scale fast reactor to a fleet of them.

According to the WNA, 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.[54]

So China might have one commercial-scale fast reactor by 2034 – but probably won't. Clearly the claim that fast reactors will be "dominating the market by about 2030" is false.

According to the WNA, China envisages 40 GW of fast reactor capacity by 2050. A far more likely scenario is that China will have 0 GW of fast reactor capacity by 2050. And even if the 40 GW target was reached, it would still only represent around one-sixth of total nuclear capacity in China in 2050 according to the WNA[55] – fast reactors still wouldn't be "dominating the market" even if these fanciful projections are realized.

Travelling waves and the non-existent 'integral fast reactor'

According to the World Nuclear Association, China General Nuclear Power and Xiamen University are reported to be cooperating on R&D into the travelling-wave fast reactor popularised by Bill Gates, but the Ministry of Science and Technology, China National Nuclear Corporation, and the State Nuclear Power Technology Company are all skeptical of the reactor concept.[56]

Perhaps the 'integral fast reactor' (IFR) championed by James Hansen – and discussed in the following section of this submission – will come to the rescue? The UK and US governments have been considering building IFRs (specifically GE Hitachi's 'PRISM' design) for plutonium disposition – but it is almost certain that both countries will choose different methods to manage plutonium stockpiles.[57]

[51] www.world-nuclear.org/info/country-profiles/countries-a-f/china--nuclear-power/
[52] Zhang Donghui / China Institute of Atomic Energy, 2016, 'Nuclear energy and Fast Reactor development in China', www.iaea.org/NuclearPower/Downloadable/Meetings/2016/2016-05-16-05-20-NPES/3.1_China_49th_TWG-FR.pdf
[53] www.world-nuclear.org/info/country-profiles/countries-a-f/china--nuclear-power/
[54] www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-fuel-cycle.aspx
[55] www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-fuel-cycle.aspx
[56] www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-fuel-cycle.aspx
[57] Jim Green, 9 Sept 2015, 'Diminishing prospects for MOX and integral fast reactors', Nuclear Monitor #810, www.wiseinternational.org/nuclear-monitor/810/diminishing-prospects-mox-and-integral-fast-reactors

A future for fast reactors?

Just 400 reactor-years of worldwide experience have been gained with fast reactors.[58] There is 42 times more experience with conventional reactors (16,850 reactor-years[59]). And most of the experience with fast reactors suggests they are more trouble than they are worth.

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.[60]

There are the 13 projects listed by the WNA[61] – but a large majority of those projects, perhaps all of them, lack both approval and funding.

France is considering building a fast reactor (ASTRID) despite the country's unhappy experience with the Phénix and Superphénix reactors. But a decision on whether to construct ASTRID will not be made until 2019/20.[62] (The performance of the Superphénix reactor was as dismal as Monju. Superphénix was meant to be the world's first commercial fast reactor but in the 13 years of its miserable existence it rarely operated – its 'Energy Unavailability Factor' was 90.8% according to the IAEA.[63])

A 2010 article in the Bulletin of the Atomic Scientists neatly summarized the worldwide failure of fast reactor technology:[64]
"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."

Allison MacFarlane, former chair of the US Nuclear Regulatory Commission, recently made this scathing assessment of fast reactor technology: "These turn out to be very expensive technologies to

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[58] World Nuclear Association, Sept 2016, 'Fast Neutron Reactors', www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx
[59] www.iaea.org/pris/
[60] Thomas B. Cochran et al., 2010, 'Fast Breeder Reactor Programs: History and Status', http://fissilematerials.org/library/rr08.pdf
[61] http://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx
[62] www.iaea.org/NuclearPower/Downloadable/Meetings/2015/2015-05-25-05-29-NPTDS/Country/7_ASTRID_project_TWG_FR_MAY_2015.pdf. See also www.nucnet.org/all-the-news/2014/05/16/france-plans-introduction-of-commercial-fast-neutron-reactors-in-2040
[63] www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=178
[64] Thomas Cochran et al., May/June 2010, 'It's time to give up on breeder reactors', http://ipfmlibrary.org/Breeders_BAS_May_June_2010.pdf

build. Many countries have tried over and over. What is truly impressive is that these many governments continue to fund a demonstrably failed technology."[65]

8. INTEGRAL FAST REACTORS

A number of Australian nuclear advocates are promoting a plan to import spent nuclear fuel (and possibly other forms of nuclear waste) and to process it for use as fuel in 'integral fast reactors' (IFRs). IFRs don't exist but they were the subject of an R&D program in the US for several decades.

That R&D program was not without controversy. Dr James Smith, a scientist who worked on an IFR R&D project in the US, was 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.[66]

IFR/ADR/PRISM − US Department of Energy report

On the basis of the R&D program in the US, GE Hitachi (GEH) says it is willing to build an IFR − which it calls 'Power Reactor Innovative Small Module' (PRISM) − if it can find a customer. The US and UK governments have shown some interest in the use of IFRs for plutonium disposition (providing proliferation resistance to separated plutonium stockpiles), and both governments have published reports on the topic.

The Plutonium Disposition Working Group of the US Department of Energy (DoE) released a report in April 2014 which considers the use of Advanced Disposition Reactors (ADR) to manage US plutonium stockpiles (mostly surplus weapons plutonium).[67] The ADR concept is similar to General Electric Hitachi's PRISM according to the DoE.

The DoE's cost estimates for ADRs are as follows:
- 'capital project point estimate': US$9.42 billion.
- operating cost estimate US$33.41 billion.
- other program costs: US$7.62 billion.

Which gives a total of US$50.45 billion, or "more than $58 billion life cycle cost when sunk costs are included." That is twice as much as the next most expensive option for plutonium management:
- immobilisation (ceramic or glass) with high-level waste: US$28.65 billion.
- irradiation of MOX in light-water reactors: US$25.12 billion.
- downblending and disposal: US$8.78 billion.

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[65] Stephen Stapczynski and Emi Urabe, 1 June 2016, 'Japan's Nuclear Holy Grail Slips Away With Operator Elusive', http://washpost.bloomberg.com/Story?docId=1376-O7Q3JD6JIJV801-5DS75Q6VPR85E6K1V77TLR120J
[66] www.faqs.org/abstracts/Zoology-and-wildlife-conservation/Fusion-programme-could-aid-terrorists-California-to-keep-energy-labs-contracts.html
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
[67] US Department of Energy, April 2014, 'Report of the Plutonium Disposition Working Group: Analysis of Surplus Weapon Grade Plutonium Disposition Options', www.nnsa.energy.gov/sites/default/files/nnsa/04-14-inlinefiles/SurplusPuDispositionOptions.pdf

- deep borehole disposal: no estimate provided.

The DoE report estimates that it would take 18 years to construct an ADR and associated facilities, with plutonium disposition beginning in 2033 and ending in 2075. Moreover, the DoE report states: "Final design of a commercial fast reactor would require significant engineering and licensing and as such carries uncertainties in being able to complete within the assumed duration."

On the technical challenges, the DoE report states:
"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 is associated with "significant technical risk" according to the DoE, and metal fuel fabrication faces "significant technical challenges" and has only been operated at the pilot scale.

IFR/PRISM/ADR advocates argued in 2011 that the first PRISM could be built in the US by 2016.[68] However the US Nuclear Regulatory Commission has yet to receive a licensing submission from GEH. There are no concrete plans for PRISMs in the US, let alone any concrete pours. According to a November 2014 report, an updated safety assessment of PRISM will be conducted by Argonne National Laboratory with a multimillion-dollar investment from the US government.[69]

IFR/PRISM – UK report

The UK Nuclear Decommissioning Authority (NDA) released a position paper in January 2014 outlining potential options for future management of separated plutonium stockpiles.[70]

The options being considered for separated plutonium management in the UK are:
- Incorporating separated plutonium into mixed uranium–plutonium oxide MOX fuel for use in conventional light-water reactors;
- Reuse in Candu Energy 'Enhanced CANDU 6' reactors;
- Reuse in 'Power Reactor Innovative Small Module' (PRISM) fast reactors proposed by General Electric Hitachi (GEH)[71];

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[68] 'Disposal of UK plutonium stocks with a climate change focus', http://bravenewclimate.com/2011/06/04/uk-pu-cc/

[69] Maxx Chatsko, 23 Nov 2014, 'General Electric Company's Advanced Nuclear Reactor Just Got a Boost From the DOE', www.fool.com/investing/general/2014/11/23/general-electric-companys-advanced-nuclear-reactor.aspx

[70] UK Nuclear Decommissioning Authority, Jan 2014, 'Progress on approaches to the management of separated plutonium – Position Paper', www.nda.gov.uk/publication/progress-on-approaches-to-the-management-of-separated-plutonium-position-paper

[71] http://gehitachiprism.com

- Non-reuse options − long-term storage followed by disposal, or immobilisation followed by disposal.

The NDA report states that reuse in CANDU reactors "remains a credible option", that MOX is a "credible and technically mature option", while PRISM "should also be considered credible, although further investigation may change this view."

The NDA report states: "Currently, we believe there is insufficient understanding of the options to confidently move into implementation and consider that significant further work must be undertaken, focussing on technical and commercial risks and uncertainties ..."

General Electric Hitachi (GEH) proposes two 311 MWe PRISM reactors with the following processes:
- conversion of separated plutonium to a sodium-bonded U/Pu/Zr metal fuel using Direct Electrolytic Reduction, Pyroprocessing and metal casting techniques;
- irradiation of this metal fuel in PRISM reactors, in a burn rather than breed mode; and
- storage of the spent fuel pending disposal (no recycle of spent fuel, in line with current UK new nuclear build assumptions).

The NDA notes that the facilities required by the PRISM approach have not been industrially demonstrated, so further development work needs to be undertaken with the cost and time to complete this work yet to be defined in detail. GEH estimates that licensing these first of a kind PRISM reactors would take around six years. GEH envisages first irradiation (following development, licensing and construction) in 14−18 years but the NDA considers that timeframe "ambitious considering delivery performance norms currently seen in the UK and European nuclear landscape".

Internal 2011 emails, released under Freedom of Information laws, revealed that the NDA said it had carried out a "high-level assessment" of PRISM and "the technology maturity for the fuel, reactor and recycling plant are considered to all be low".[72]

The NDA states that it has carried out a 'Generic Disposability Assessment' which found that, "whilst challenging, a disposal safety case can probably be made for disposal of sodium bonded PRISM Spent Fuel derived from the irradiation of the plutonium stocks in the UK." GEH proposes methods to remove the sodium from spent fuel in the event that a disposability safety case cannot be made.

IFRs are promoted on the grounds that they could recycle spent fuel repeatedly, leaving only relatively short-lived fission products (with half lives of 10−30 years) to be disposed of as waste. But the aims of the UK PRISM proposal are far more modest. GEH's Eric Loewen says: "What we're proposing is to disposition it; that means irradiating it in the reactor so that the plutonium is fissioned and the material is at the same radiation standard as spent fuel."[73]

The NDA report states that GEH believes that PRISMs could be implemented "under commercial arrangements". But it is unclear what that means. GEH is seeking funding from the US Export-Import Bank.

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[72] Rob Edwards, 24 Jan 2012, 'Plans for Sellafield plutonium reactor rejected', www.guardian.co.uk/environment/2012/jan/24/sellafield-plutonium-reactor-plans-rejected
[73] Stuart Nathan, 13 May 2013, 'Prism project: A proposal for the UK's problem plutonium', www.theengineer.co.uk/energy-and-environment/in-depth/prism-project-a-proposal-for-the-uks-problem-plutonium/1016276.article

GEH refuses to release estimates of PRISM capital and operating costs, saying they are "commercially sensitive".[74]

An August 2015 report states that the Candu option seems to be emerging as a favourite for plutonium disposition in the UK, and that GEH is 'hedging its bets' by working with Candu Energy to develop the Candu approach.[75]

Assessing the claims of IFR advocates

An IFR advocate claims that the "first one [1 GWe IFR] will probably cost around [US]$1 to $2 billion".[76] That claim is inconsistent with the information provided in the UK and US reports (albeit the case that the UK and US reports consider a range of costs in addition to capital costs).

An IFR advocate claims that GEH could get a PRISM reactor "up and running in 5 years – the PRISM is fully proven in engineering terms and basically ready to go."[77] That claim is inconsistent with the information provided in the UK and US reports (see above).

An IFR advocate claims that: "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."[78]

That claim is inconsistent with the UK NDA report which raises questions about the 'disposal safety case' for sodium bonded PRISM spent fuel. Advocates would argue that IFRs could *theoretically* recycle spent fuel until nothing is left but relatively short-lived fission products. However attractive theories have a history of giving rise to significant problems, e.g. a global legacy of 270 tonnes of separated plutonium despite the theoretical attractiveness of reprocessing to facilitate waste disposal; a legacy of failed fast reactor projects; and failed white elephants such as the MOX and THORP plants at Sellafield (and numerous others around the world).

Advocates promote the 'proliferation resistance' of the IFR fuel cycle. Theoretically, IFRs could consume more plutonium than they produce, and plutonium would never be separated from other actinides in a modified form of reprocessing called pyroprocessing. But in the case of the UK:

- proliferation risks are heightened by separating plutonium from spent fuel;
- internal 2011 emails reveal that the NDA is concerned about increased proliferation risks from converting plutonium oxide powder into metal PRISM fuel: "This would introduce more security/proliferation risk."[79]; and
- PRISMs will incorporate plutonium into spent fuel ... which begs the question: why separate plutonium from spent fuel in the first place?

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[74] http://gehitachiprism.com/faqs/ [Accessed 30 July 2015]
[75] August 2015, 'Slow Progress on Plutonium Stockpiles', nuClear news No.76, www.no2nuclearpower.org.uk/nuclearnews/NuClearNewsNo76.pdf
[76] http://skirsch.com/politics/globalwarming/ifrQandA.htm
[77] Mark Lynas, 1 March 2012, 'UK moves a step closer to nuclear waste solution', www.marklynas.org/2012/03/uk-moves-a-step-closer-to-nuclear-waste-solution/
[78] www.marklynas.org/2012/03/uk-moves-a-step-closer-to-nuclear-waste-solution/
[79] Rob Edwards, 24 Jan 2012, 'Plans for Sellafield plutonium reactor rejected', www.guardian.co.uk/environment/2012/jan/24/sellafield-plutonium-reactor-plans-rejected

More generally, claims that IFRs would be proliferation-resistant do not stand up to scrutiny. For example an IFR advocate claims they "cannot be used to generate weapons-grade material."[80] But IFRs could be used to produce plutonium for weapons.[81] 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."[82]

IFR advocates claim that there is be very little risk of a serious accident. Such claims are often made about reactor concepts that exist only on paper and they should be treated with scepticism. As a nuclear industry insider puts it: "We know that the paper-moderated, ink-cooled reactor is the safest of all." He went on to warn that: "All kinds of unexpected problems may occur after a project has been launched."[83] Likewise, nuclear engineer David Lochbaum says that: "The IFR looks good on paper. So good, in fact, that we should leave it on paper. For it only gets ugly in moving from blueprint to backyard."[84] In addition to that pithy comment, Lochbaum discusses some of the technical issues and risks associated with IFRs, raising serious questions and doubts about the safety claims made by IFR advocates.

9. THORIUM

There is a great deal of enthusiastic rhetoric and promotion regarding thorium. One advocate states: "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 consume existing waste."[85]

The adage that if a thing sounds too good to be true then it probably is not applies here and such claims do not stand up to scrutiny.

The World Nuclear Association (WNA) notes that the commercialization of thorium fuels faces some "significant hurdles in terms of building an economic case to undertake the necessary development work." The WNA states:[86]

"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.

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

[81] Friends of the Earth, Australia, 'Nuclear Weapons and 'Generation 4' Reactors', www.foe.org.au/anti-nuclear/issues/nfc/power-weapons/g4nw

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

[83] Quoted in 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, www.greenpeace.org/international/press/reports/nuclearreactorhazards

[84] http://skirsch.com/politics/globalwarming/ifrUCSresponse.pdf

[85] Tim Dean, 16 March 2011, 'The greener nuclear alternative', www.abc.net.au/unleashed/45178.html

[86] www.world-nuclear.org/info/Current-and-Future-Generation/Thorium/

"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:[87]

"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:[88]
"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.
"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.[89]

Nuclear physicist Prof. George Dracoulis writes:
"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."[10]

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[87] 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
[88] 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
[89] 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

The 2015 report[90] 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."[91]

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."[92] 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."

Thorium and proliferation

Claims that thorium reactors would be proliferation-resistant or proliferation-proof do not stand up to scrutiny.[93] Irradiation of thorium-232 produces uranium-233, which can be and has been used in nuclear weapons.

The World Nuclear Association states:[94]
"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.[95]

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[90] 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

[91] 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

[92] 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

[93] www.foe.org.au/anti-nuclear/issues/nfc/power-weapons/thorium

[94] www.world-nuclear.org/info/Current-and-Future-Generation/Thorium/

[95] Nigel Marks, 2 March 2015, 'Should Australia consider thorium nuclear power?',

Uranium-233 is contaminated with uranium-232 but there are ways around that problem. Kang and von Hippel note:[96]
"[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:[97]
"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 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."

10. SMALL MODULAR REACTORS

The Australian governments Energy Green Paper released in September 2014 also reflects the current small-is-beautiful nuclear rhetoric: "The main development in technology since 2006 has

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http://theconversation.com/should-australia-consider-thorium-nuclear-power-37850

[96] 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

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

been further work on Small Modular Reactors (SMRs). SMRs have the potential to be flexibly deployed, as they are a simpler 'plug-in' technology that does not require the same level of operating skills and access to water as traditional, large reactors."[98]

The rhetoric doesn't match reality and interest in SMRs is on the wane. Thomas W. Overton, associate editor of POWER magazine, wrote in a September 2014 article:
"At the graveyard wherein resides the "nuclear renaissance" of the 2000s, a new occupant appears to be moving in: the small modular reactor (SMR). ... Over the past year, the SMR industry has been bumping up against an uncomfortable and not-entirely-unpredictable problem: It appears that no one actually wants to buy one."[99]

Overton notes that a central premise of SMR rhetoric is large-scale standardised manufacturing producing many identical plants:
"It's an attractive idea. But it's also one that depends on someone building that massive supply chain, since none of it currently exists. ... That money would presumably come from customer orders − if there were any."

Likewise, Glenn George from KPMG states:
"I think that investors are in a wait-and-see mode regarding development of the SMR market. ... Investors will want to see SMR learning-curve effects, but a chicken-and-egg situation is at work: Decreased cost comes from production of multiple units over time, yet such production requires investment in the first place."[100]

Dr Mark Cooper, Senior Fellow for Economic Analysis at the Institute for Energy and the Environment, Vermont Law School, notes that two US corporations are pulling out of SMR development because they cannot find customers (Westinghouse) or major investors (Babcock and Wilcox). Cooper points to some economic constraints:
"SMR technology will suffer disproportionately from material cost increases because they use more material per MW of capacity. Higher costs will result from: lost economies of scale; higher operating costs; and higher decommissioning costs. Cost estimates that assume quick design approval and deployment are certain to prove to be wildly optimistic."[101]

Westinghouse CEO Danny Roderick said in January 2014: "The problem I have with SMRs is not the technology, it's not the deployment − it's that there's no customers."[102]

Academics M.V. Ramana and Zia Mian state in their detailed analysis of SMRs:[103]
"Proponents of the development and large scale deployment of small modular reactors suggest that this approach to nuclear power technology and fuel cycles can resolve the four key problems facing nuclear power today: costs, safety, waste, and proliferation. Nuclear developers and vendors seek to encode as many if not all of these priorities into the designs of their specific nuclear reactor. The

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[98] http://ewp.industry.gov.au/files/egp/energy_green_paper.pdf
[99] Thomas W. Overton, 1 Sept 2014, 'What Went Wrong with SMRs?', www.powermag.com/what-went-wrong-with-smrs/
[100] Peter Taberner, 3 March 2015, 'SMRs: private investors call for track record and big government orders', http://analysis.nuclearenergyinsider.com/small-modular-reactors/smrs-private-investors-call-track-record-and-big-government-orders
[101] www.nirs.org/reactorwatch/newreactors/cooper-smrsaretheproblemnotthesolution.pdf
[102] www.post-gazette.com/business/2014/02/02/Westinghouse-backs-off-small-nuclear-plants/stories/201402020074
[103] www.sciencedirect.com/science/article/pii/S2214629614000486

technical reality, however, is that each of these priorities can drive the requirements on the reactor design in different, sometimes opposing, directions. Of the different major SMR designs under development, it seems none meets all four of these challenges simultaneously. In most, if not all designs, it is likely that addressing one of the four problems will involve choices that make one or more of the other problems worse."

Likewise, Kennette Benedict, Executive Director of the *Bulletin of the Atomic Scientists*, states: "Small modular nuclear reactors may be attractive, but they will not, in themselves, offer satisfactory solutions to the most pressing problems of nuclear energy: high cost, safety, and weapons proliferation."[104]

Argentina is constructing a 27 MWe reactor − but the estimated cost of US$446 million equates US$17.8 billion / gigawatt (GW)[105] SMRs will remain expensive curiosities unless and until a large-scale manufacturing chain is established – and no country or company has any intention of building that supply chain given the very large financial risks involved.

The July 2015 edition of the World Nuclear Industry Status Report includes an examination of SMRs that found:[106]
"The concept for Small Modular Reactors (SMR) has been around for decades. Over a dozen basic designs have been discussed.
"In the U.S., where the government has been funding SMR development since the 1990s, the Nuclear Regulatory Commission has still not received a licensing application for any SMR design.
"In Russia, a Floating Point Unit design, a sort of swimming reactor, was licensed in 2002. The construction of two reactors began in 2007 but has been delayed repeatedly, partly for financial reasons.
"In South Korea an SMR design called System-Integrated Modular Advanced Reactor (SMART) has been under development for 20 years. The design was approved by the regulator in 2012, but no unit has been sold.
"In China, one SMR of the high-temperature gas cooled reactor is under construction.
"In South Africa, the Pebble Bed Modular Reactor − for a long time considered the most advanced SMR project in the world − was abandoned in 2010, after public expenditure of about US$1 billion, because it attracted no private investors or customers. The design was never completed.
"India has been developing an Advanced Heavy Water Reactor (AHWR) since the 1990s, but none is under construction.
"In February 2014, Argentina started construction on a small unit, based on the pressurized water reactor, called CAREM, a domestic design that has been under development since the 1980s, reportedly at a cost of US$17,000 per installed kWe, a record for reactors currently under construction in the world.
"Despite extensive government aid, U.S. development of SMRs is gaining far less market traction than publicity, as SMRs are initially far costlier than uncompetitively costly large reactors, their postulated learning curve relies upon an ability to reduce their cost has never been demonstrated anywhere for nuclear technology, and they face a formidable competitive landscape dominated by efficiency and renewable technologies already decades ahead in capturing their own economies of mass production."

Former World Nuclear Industry executive Steve Kidd wrote in a June 2015 article:[107]

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[104] http://thebulletin.org/are-small-nuclear-reactors-answer
[105] www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html
[106] See pp.68−78 in Mycle Schneider, Antony Froggatt et al., July 2015, 'World Nuclear Industry Status Report 2015', www.worldnuclearreport.org/-2015-.html

"SMRs are heavily promoted today as a viable solution to some of the problems experienced by projects to build large light water reactors (LWRs). Assuming they are technically viable, the smaller capital expenditure needed to build a largely factory-built smaller unit and the shorter construction period are certainly attractive features. And if electricity production is moving away from large centralised generating units into a distributed power model, smaller nuclear units may still have a chance. They may have a chance today in remote areas in developed countries that don't have easy grid access.
"Lower cost, however, doesn't necessarily mean better economics. Smaller nuclear reactors were developed back in the 1950s but the sensible decision was made to take advantage of nuclear's real unique selling proposition. That is the ability to produce huge quantities of electricity very reliably in one place, with a small fuel input and minimal environmental impact. Reactor units became progressively larger in an attempt to capture economies of scale in construction costs, but also (and very importantly) to minimise operating and maintenance (O&M) expenses. ...
"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, 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 costs are a concern. A substantial part of these are fixed, irrespective of the size of reactor."

South Korea may have found a model to unlock the potential of SMRs: collaboration with a restrictive Middle Eastern state coupled with extensive nuclear technology transfer. 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 three-year 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 desalinization. The cost of building the first SMART reactor in Saudi Arabia is estimated at US$1 billion.[108]

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.

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 world-wide.[109]

The joint partnership − and the extensive technology transfer and training it entails − would take Saudi Arabia a long way 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.[110]

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[107] Steve Kidd, 11 June 2015, 'Nuclear myths – is the industry also guilty?', www.neimagazine.com/opinion/opinionnuclear-myths-is-the-industry-also-guilty-4598343/
[108] 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
[109] KACARE, 3 March 2015, 'MOU's Signature', www.kacare.gov.sa/en/?p=1667
[110] 18 Sept 2014, 'Saudi Arabia's nuclear power program and its weapons ambitions', Nuclear Monitor, Issue #791, www.wiseinternational.org/node/4195

Wall Street Journal reporters noted on 11 March 2015:
"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."[111]

11. FUSION SCIENTIST DEBUNKS FUSION

The *Bulletin of the Atomic Scientists* has recently 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.[112] Jassby writes:

"[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. 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.

Jassby further states: "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 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 ..."

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[111] 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
[112] Daniel Jassby, 19 April 2017, 'Fusion reactors: Not what they're cracked up to be', http://thebulletin.org/fusion-reactors-not-what-they%E2%80%99re-cracked-be10699

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.

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 Jassby's comment about deuterium-deuterium systems posing greater proliferation risks than deuterium-tritium systems. He writes: "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," Jassby writes.

It isn't mentioned in 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."[113]

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 fusion reactors would need to be much larger to overcome the 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 masses of highly radioactive material that must eventually be transported offsite for burial",

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[113] Khidhir Hamza, Sep/Oct 1998, 'Inside Saddam's Secret Nuclear Program', Bulletin of the Atomic Scientists, Vol. 54, No. 5, www.iraqwatch.org/perspectives/bas-hamza-iraqnuke-10-98.htm

and non-structural components inside the reaction vessel and in the blanket will also become highly radioactive by neutron activation.

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

Tritium leakage is another problem. Jassby writes: "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. Jassby writes: "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."

Because of these and other problems, "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. Jassby states that it "is inconceivable that the total operating costs of a fusion reactor will be less than that of a fission reactor".

Jassby concludes:

"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."

Conclusion: Our organisations share the concerns outlined earlier around terrestrial nuclear fusion, however we strongly support harnessing fusion power from an existing source that is safely located, removed from the threats of error and terror, free of the massive concerns and costs involved with the effective management of waste and is commissioned and operating now.

Solar energy and other forms of renewable power are the future of a secure and sustainable global energy future. The challenge is no longer about how to generate energy, rather how to best store and transfer it.

We maintain that the various Generation IV nuclear systems are continuing the pattern of a long history of promise and a low level of delivery. They are costly, complex and constrained by many of the key areas of concern obvious with conventional reactors, including costs, safety, waste and proliferation.

We believe that Australia's involvement with Generation IV promotion would be a distraction from the real energy challenges and solutions and not consistent with global energy trends. It is also not consistent with clear action to address either nuclear non-proliferation or energy and climate change and is inconsistent with Australian prohibitions and community expectations on nuclear power.

We would welcome the opportunity to speak to these concerns and further detail our assessment of the various Generation four technologies at any future Committee hearing.