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The 'advanced' nuclear power sector is dystopian

Author: Jim Green – Nuclear Monitor editor

"Any plant you haven't built yet is always more efficient than the one you have built. This is obvious. They are all efficient when you haven't done anything on them, in the talking stage. Then they are all efficient, they are all cheap. They are all easy to build, and none have any problems."

– Admiral Hyman Rickover (who played a leading role in the development of the US nuclear industry), Congressional testimony, 1957.

The 'advanced' nuclear sector – comprising pretty much everything except large conventional reactors – isn't 'advanced' and it isn't advancing. The next advanced reactor to commence operation will be Russia's floating nuclear power plant, designed to help exploit fossil fuel reserves in the Arctic[1] – fossil fuel reserves that are more accessible because of climate change. That isn't advanced – it is dystopian.

Russia's enthusiastic pursuit of nuclear-powered icebreaker ships (nine such ships are planned by 2035) is closely connected to its agenda of establishing military and economic control of the Northern Sea Route – a route that owes its existence to climate change.[2]

The deputy director of China's State Administration for Science, Technology and Industry for National Defense said in 2017 that China will prioritize the development of floating nuclear power plants in order to support its offshore oil and gas activities, and its presence in the Paracel and Spratly Islands.[3] China General Nuclear Power Group (CGN) says the purpose of its partly-built ACPR50S demonstration reactor is to develop floating nuclear power plants for oilfield exploitation in the Bohai Sea and deep-water oil and gas development in the South China Sea.[4]

State-owned China National Nuclear Power Co. said that a joint venture announced in August 2017 will seek to strengthen China's nuclear power capabilities in line with its ambitions to "become a strong maritime power".[3] As many as 20 floating nuclear power plants are planned.[3]

Further, floating nuclear plants could provide power for artificial islands in the South China Sea that were built to project military power in the region.[3] Thus floating nuclear power plants become embroiled in the ongoing international controversy over China's artificial islands and might be in the firing line if, for example, a US "freedom of navigation operation" turns into a freedom of navigation shooting battle. Carlyle Thayer from the Australian Defense Force Academy said the floating nuclear plants would "raise the cost of the conflict" in the region because of the potential release of radioactive materials from a damaged floating nuclear plant.[3] Military assets on artificial islands will be used to protect floating nuclear power plant/s.[3]

The floating nuclear power programs of China and Russia, along with their nuclear-powered icebreaker programs, are advancing fossil fuel mining and the projection of military and geopolitical power in support of those operations.

Small reactors might advance Canada's greenhouse emissions – one potential application is providing power and heat for the extraction of hydrocarbons from oil sands.[5] (That said, costs and other factors make it unlikely that reactors will be deployed for oil sand mining.)

Fusion could provide another example of 'advanced' nuclear advancing climate change. In 2017, the *Bulletin of the Atomic Scientists* published a detailed critique of fusion power written by fusion scientist Dr. Daniel Jassby, a former principal research physicist at the Princeton Plasma Physics Lab.[6,7] Dr. Jassby says that the "massive energy investment" to half-build the International Thermonuclear Experimental Reactor (ITER) in France "has been largely provided by fossil fuels, leaving an unfathomably large 'carbon footprint' for site preparation and construction of all the supporting facilities, as well as the reactor itself."[7] ITER is a test reactor and will never generate electricity – so the energy investment and carbon debt will never be repaid.

Dr. Jassby's description of ITER borders on the dystopian:[7]

"ITER will be, manifestly, a havoc-wreaking neutron source fueled by tritium produced in fission reactors, powered by hundreds of megawatts of electricity from the regional electric grid, and demanding unprecedented cooling water resources. Neutron damage will be intensified while the other characteristics will endure in any subsequent fusion reactor that attempts to generate enough electricity to exceed all the energy sinks identified herein. When confronted by this reality, even the most starry-eyed energy planners may abandon fusion."

Nuclear's greatest potential contribution to climate change would be through the displacement of technologies (esp. renewables) and programs (esp. energy efficiency) that can make a greater, faster, cheaper contribution to climate change abatement. The latest Lazard report on levelized costs of electricity finds that nuclear (US$118–192 per megawatt-hour) is more uncompetitive than ever compared to utility-scale solar ($32–42/MWh) and onshore wind ($28–54/MWh).[8]

Advanced nuclear will likely make the economic problem worse. A 2015 article by the International Energy Agency and the OECD's Nuclear Energy Agency states that "generation IV technologies aim to be at least as competitive as generation III technologies ... though the additional complexity of these designs, the need to develop a specific supply chain for these reactors and the development of the associated fuel cycles will make this a challenging task."[9]

Amory Lovins comments on the endless clamor for ever-greater subsidies to rescue nuclear power from economic oblivion:[10]

"Such anti-market monkeybusiness cannot indefinitely forestall the victory of cheaper competitors, but it can delay and diminish climate protection while transferring tens of billions of unearned dollars from taxpayers and customers to nuclear owners. That would save less carbon, more slowly, than letting the best buys win, yet some politicians fervently favoring climate protection mistakenly endorse it, and most journalists reinforce their misconception."

Nuclear waste

Some 'advanced' reactors could theoretically consume more nuclear waste than they produce. That sounds great – until you dig into the detail.

An article in the *Bulletin of the Atomic Scientists*, co-authored by Lindsay Krall and Prof. Allison Macfarlane (a former chair of the US Nuclear Regulatory Commission), states that "molten salt reactors and sodium-cooled fast reactors – due to the unusual chemical compositions of their fuels – will actually exacerbate spent fuel storage and disposal issues."[11]

A separate, less technical article in the *Bulletin of the Atomic Scientists* – also co-authored by Prof. Macfarlane – explains the problems in simple terms:[12]

"It's tempting to believe that having new nuclear power plants that serve, to some degree, as nuclear garbage disposals means there is no need for a nuclear garbage dump, but this isn't really the case. Even in an optimistic assessment, these new plants will still produce significant amounts of high-level, long-lived waste. What's more, new fuel forms used in some of these advanced reactors could pose waste disposal challenges not seen to date.

"Some of these new reactors would use molten salt-based fuels that, when exposed to water, form highly corrosive hydrofluoric acid. Therefore, reprocessing (or some form of "conditioning") the waste will likely be required for safety reasons before disposal.

"Sodium-cooled fast reactors – a "new" technology proposed to be used in some advanced reactors, including the Bill Gates-funded TerraPower reactors – face their own disposal challenges. These include dealing with the metallic uranium fuel which is pyrophoric (that is, prone to spontaneous combustion) and would need to be reprocessed into a safer form for disposal.

"Unconventional reactors may reduce the level of some nuclear isotopes in the spent fuel they produce, but that won't change what really drives requirements for our future nuclear waste repository: the heat production of spent fuel and amount of long-lived radionuclides in the waste. To put it another way, the new reactors will still need a waste repository, and it will likely need to be just as large as a repository for the waste produced by the current crop of conventional reactors.

"Recycling and minimizing – even eliminating – the waste streams that many industries produce is responsible and prudent behavior. But in the context of nuclear energy, recycling is expensive, dirty, and ultimately dangerous. Reprocessing spent nuclear fuel – which some advanced reactor designs require for safety reasons – actually produces fissile material that could be used to power nuclear weapons. This is precisely why the United States has avoided the reprocessing of spent nuclear fuel for the last four decades, despite having the world's largest number of commercial nuclear power plants.

"Continuing research on how to deal with nuclear waste is a great idea. But building expensive prototypes of reactors whose fuel requires reprocessing, on the belief that such reactors will solve the nuclear waste problem in America, is misguided. At the same time, discounting the notion that a US move into reprocessing might spur other countries to develop this same technology – a technology they could secretly exploit to produce nuclear weapons – is shortsighted and damaging to US national and world security."

The Molten Salt Reactor Experiment in the US left a troubling legacy of radioactive waste streams.[13] Krall and Macfarlane state:[11]

"In 1985, the Energy Department thought that the used Molten Salt Reactor Experiment fuel could be safely stored for decades. But by 1994, workers observed that radiolytic decomposition of uranium tetrafluoride had generated fluorine gases and uranium hexafluoride enriched in fissile isotopes, which had migrated throughout the offgas system and generated corrosive hydrofluoric acid. The likelihood of a criticality accident was high under these conditions."

Likewise, US government agencies are still working on the problem of what to do with waste arising from testing thorium and uranium reactor fuel at the Consolidated Edison Indian Point-1 reactor in New York in the 1960s.[14]

The subclass of sodium-cooled fast reactors called 'integral fast reactors' (IFRs) could theoretically gobble up nuclear waste and convert it into low-carbon electricity, using a process called pyroprocessing. But an IFR R&D program in Idaho – the Experimental Breeder Reactor II – has left a mess that the Department of Energy (DOE) is still struggling to deal with. This saga is detailed in a 2017 article[15] and a longer report[16] by the Union of Concerned Scientists' senior scientist Dr. Edwin Lyman, drawing on documents obtained under Freedom of Information legislation.

Dr. Lyman writes:[15]

"Pyroprocessing has taken one potentially difficult form of nuclear waste and converted it into multiple challenging forms of nuclear waste. DOE has spent hundreds of millions of dollars only to magnify, rather than simplify, the waste problem. … The FOIA documents we obtained have revealed yet another DOE tale of vast sums of public money being wasted on an unproven technology that has fallen far short of the unrealistic projections that DOE used to sell the project".

Krall and Macfarlane discuss the same fiasco:[11]

"Furthermore, the Energy Department discovered impediments to the geologic disposal of their sodium-bonded fuels after the Experimental Breeder Reactor and the Fast Flux Test Facility were defunded in 1994. Citing repository criteria of the NRC and the Office of Civilian Radioactive Waste Management that prohibit the presence of pyrophoric and/or chemically reactive materials in waste packages, the Energy Department decided to electro-metallurgically treat the sodium-bonded spent fuel using the Idaho National Lab pyroprocessing technology before emplacement in a repository.

"The department explained its reasoning this way: '[T]he metallic sodium is highly reactive. The metallic uranium is also reactive and potentially pyrophoric, and in some cases the fuel contains highly enriched uranium, which would require criticality control measures.'

"Several parties, including the Environmental Protection Agency, noted the underwhelming scientific and economic bases for the decision to chemically deactivate the fuel by electrometallurgical treatment. Nevertheless, the Energy Department dismissed direct disposal or alternative treatment options, then planned to pyroprocess 26 metric tons of sodium-bonded fuel by 2013 at a cost of approximately $550 million; the process would include conversion of the byproducts – metallic uranium and a sodium chloride-based mixture of plutonium and fission products – to oxide and zeolite-based waste forms, respectively.

"Neither the deadline nor the budget was met, and internal Energy Department documents have revealed that the untreated fuel is degrading in storage, after corrosion of stainless-steel claddings allowed oxygen and moisture to penetrate some of the fuel elements. In at least one case, reaction between water and metallic uranium caused the fuel to burn (literally). The compromised fuel pins are no longer candidates for pyroprocessing and so will remain in storage indefinitely."

Small modular reactors and nuclear waste

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

The 2015/16 South Australian Nuclear Fuel Cycle Royal Commission said in its Final Report that "SMRs have lower thermal efficiency than large reactors, which generally translates to higher fuel consumption and spent fuel volumes over the life of a reactor."[17]

Likewise, M.V. Ramana notes that "a smaller reactor, at least the water-cooled reactors that are most likely to be built earliest, will produce more, not less, nuclear waste per unit of electricity they generate because of lower efficiencies."[18]

A 2016 European Commission document states due to the loss of economies of scale, the decommissioning and waste management unit costs of SMRs "will probably be higher than those of a large reactor (some analyses state that between two and three times higher)."[19]

Fusion and nuclear waste

Dr. Jassby writes in the *Bulletin of the Atomic Scientists* that 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.[6] Moreover, 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", and non-structural components inside the reaction vessel and in the blanket will also become highly radioactive by neutron activation.[6]

The International Thermonuclear Experimental Reactor under construction in France will eventually produce "a staggering 30,000 tons of radioactive waste," Dr. Jassby writes.[7]

Nuclear weapons, nuclear winter

Some 'advanced' reactors could theoretically consume more fissile (explosive) nuclear material than they produce. That sounds great – until you dig into the detail.

After Russia's floating nuclear plant, the next 'advanced' reactor to commence operation may be the Prototype Fast Breeder Reactor (PFBR) in India. The PFBR has a blanket with thorium and uranium to breed fissile uranium-233 and plutonium respectively – in other words, it will be ideal for weapons production.

India plans to use fast breeder reactors (a.k.a. fast neutron reactors) to produce weapon-grade plutonium for use as the initial 'driver' fuel in thorium reactors (which would themselves prevent further proliferation risks through the breeding of fissile uranium-233 or plutonium-239). As John Carlson, the former Director-General of the Australian Safeguards and Non-proliferation Office, has repeatedly noted, those plans are highly problematic with respect to weapons proliferation and security.[20]

India's 'advanced' reactor program isn't advanced. It is dystopian and dangerous, and it fans regional tensions and proliferation concerns in South Asia – all the more so since India refuses to allow International Atomic Energy Agency safeguards inspections of its advanced nuclear power program.

And if those regional tensions boil over into nuclear warfare, catastrophic climate change will likely result.[21] Fossil fuels provide the surest route to catastrophic climate change; nuclear warfare provides the quickest route.

Advanced reactor types and weapons proliferation

Krall and Macfarlane raise proliferation concerns about 'integral fast reactor' and molten salt reactor concepts: "Pyroprocessing and fluoride volatility-reductive extraction systems optimized for spent fuel treatment can – through minor changes to the chemical conditions – also extract plutonium (or uranium 233 bred from thorium)."[22]

There are broader proliferation risks associated with fast neutron reactors (including their use to produce fissile material for weapons) and associated facilities, especially reprocessing.[23] Japan's experience is nothing if not dystopian. The country's plutonium program – reprocessing and fast reactors – clearly fans regional proliferation tensions. The Monju reactor rarely operated and has been shut down. The Rokkasho reprocessing plant is more than 20 years behind schedule and cost estimates have rocketed. Altogether, Japan is spending roughly ¥3.7 trillion (US$34 billion) on Monju (¥1.5 trillion) and Rokkasho (¥2.2 trillion) – for a reactor that rarely operated and a reprocessing plant that has not yet been completed, that worsens regional proliferation tensions, that will serve no useful purpose if it ever operates … and that accomplishes all that at enormous expense.

Claims that thorium reactors would be proliferation-resistant or proliferation-proof do not stand up to scrutiny.[24,25] Thorium irradiation produces fissile uranium-233, which can be and has been used in nuclear weapons. The initial driver fuel (typically plutonium or enriched uranium) poses additional proliferation risks – as the above-mentioned example of India demonstrates. John Carlson, former Director-General of the Australian Safeguards and Non-proliferation Office, states: "Arguments that the thorium fuel cycle is inherently proliferation resistant are overstated. In some circumstances the thorium cycle could involve significant proliferation risks."[26]

Fusion has yet to generate a single Watt of useful electricity but it has already contributed to proliferation problems. According to Khidhir Hamza, a senior nuclear scientist involved in Iraq's weapons program in the 1980s: "Iraq took full advantage of the IAEA's recommendation in the mid 1980s to start a plasma physics program for "peaceful" fusion research. We thought that buying a plasma focus device ... would provide an excellent cover for buying and learning about fast electronics technology, which could be used to trigger atomic bombs."[27]

Dr. Jassby notes that 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. He further states that a fusion reactor fueled only with deuterium would be a "singularly dangerous tool for nuclear proliferation".[6]

There are disturbing connections between small modular reactors, weapons proliferation and militarism more generally, as discussed in Nuclear Monitor #872–73.[28-30]

A non-exhaustive list of those connections includes:

The potential use of SMRs to produce fissile material for weapons (they could be the proliferator's technology of choice) and the history of small reactors being used for just that purpose (e.g. North Korea's 'experimental power reactor' or India's research reactors).[28]

A subsidiary of Holtec International has actively sought a military role, inviting the National Nuclear Security Administration to consider the feasibility of using a proposed SMR to produce tritium, used to boost the explosive yield of the US nuclear weapons arsenal.[31]

The fuel requirements of SMRs can be and has been used to justify the development of enrichment technology (thus increasing the risk of civil enrichment plants being used to produce highly-enriched uranium for weapons). A case in point is the US government's funding allocation to kick-start a domestic uranium enrichment project in Ohio. The HALEU Demonstration Program will aim to produce 19.75%-enriched 'high assay low enriched uranium' (HALEU) using US-designed and operated centrifuge technology. The project is being sold as a step towards domestic production of enriched uranium for 'advanced reactors' (including SMRs) but there is also a military agenda – accommodating the Navy's long-term 'need' for additional highly enriched uranium to fuel its reactors.[28]

Another 'advanced' research project in the US – a proposed 'versatile test reactor' – also poses proliferation and security risks. Dr. Edwin Lyman from the Union of Concerned Scientists states: "What may not be clear from the name is that this facility itself would be an experimental fast reactor, likely fueled with weapon-usable plutonium. Compared to conventional light-water reactors, fast reactors are less safe, more expensive, and more difficult to operate and repair. But the biggest problem with this technology is that it typically requires the use of such weapon-usable fuels as plutonium, increasing the risk of nuclear terrorism."[32]

Some SMR companies in the UK are promoting the case for subsidies by talking up the potential contribution of an SMR program to the weapons complex.[33] For example, Rolls-Royce states that "the expansion of a nuclear-capable skilled workforce through a civil nuclear UK SMR programme would relieve the Ministry of Defence of the burden of developing and retaining skills and capability."[34]

SMRs are being promoted for potential use to power military bases and even forward operating bases in the US.[30]

As mentioned, Russia[1] and China[3] are deploying floating nuclear power plants (and nuclear-powered icebreakers) to project military and economic control over various regions (the Arctic, South China Sea, etc.).

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The 'advanced' nuclear power sector isn't advancing – thankfully

Author: Jim Green – Nuclear Monitor editor

The 'advanced' nuclear power sector isn't advanced – it is dystopian. And it isn't advancing, thankfully. Many 'advanced' reactor projects are promoted – there are lists of them, even lists of lists[1] – but meaningful funding, from governments and industry alike, is lacking.[2] Kevin Anderson, Project Director for *Nuclear Energy Insider*, noted earlier this year that there "is unprecedented growth in companies proposing design alternatives for the future of nuclear, but precious little progress in terms of market-ready solutions."[3]

In the US, even if all the private-sector Generation IV R&D funding was pooled together (an estimated US$1.3 billion[4]), it is unlikely that it would suffice to build a single prototype reactor. An article by pro-nuclear researchers from Carnegie Mellon University's Department of Engineering and Public Policy, published in the *Proceedings of the National Academy of Science* in 2018, argues that no US advanced reactor design will be commercialized before mid-century and that purported benefits remain "speculative".[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] IRSN is also skeptical about safety claims: "At the present stage of development, IRSN does not notice evidence that leads to conclude that the systems under review are likely to offer a significantly improved level of safety compared with Generation III reactors ... "[5]

The US Government Accountability Office released a report in July 2015 on the status of small modular reactors (SMRs) and other 'advanced' reactor concepts in the US.[6] The report concluded:

"While light water SMRs and advanced reactors may provide some benefits, their development and deployment face a number of challenges. Both SMRs and advanced reactors require additional technical and engineering work to demonstrate reactor safety and economics ... Depending on how they are resolved, these technical challenges may result in higher-cost reactors than anticipated, making them less competitive with large LWRs [light water reactors] or power plants using other fuels ... Both light water SMRs and advanced reactors face additional challenges related to the time, cost, and uncertainty associated with developing, certifying or licensing, and deploying new reactor technology, with advanced reactor designs generally facing greater challenges than light water SMR designs. It is a multi-decade process, 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."

The 2015/16 South Australian Nuclear Fuel Cycle Royal Commission concluded:[7]

"[A]dvanced fast reactors or reactors with other innovative designs are unlikely to be feasible or viable in South Australia in the foreseeable future. No licensed and commercially proven design is currently operating. Development to that point would require substantial capital investment. Moreover, the electricity generated has not been demonstrated to be cost-competitive with current light water reactor designs."

Fusion will likely never be commercialized. Commenting on problems with the supply and usage of both tritium and deuterium fuel, the sizable problem of parasitic energy consumption, and the inevitability that fusion reactors would share many of the drawbacks of fission reactors, fusion scientist Dr. Daniel Jassby states:[8]

"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.""

Thorium is a very long way from commercial deployment.[9] A 2012 report by the UK National Nuclear Laboratory states "more work is needed at the fundamental level to establish the basic knowledge and understanding", "thorium reprocessing and waste management are poorly understood", and the thorium fuel cycle "cannot be considered to be mature in any area."[10] The World Nuclear Association notes that the commercialization of thorium fuels faces some "significant hurdles" and 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."[11]

While there is a great deal of hype about small modular reactors (SMRs) from the nuclear industry and its enthusiasts, informed opinion is skeptical. For example, a 2017 Lloyd's Register report was based on the insights of almost 600 professionals and experts from utilities, distributors, operators and manufacturers who predict that SMRs have a "low likelihood of eventual take-up, and will have a minimal impact when they do arrive".[12] The OECD's Nuclear Energy Agency estimates a very modest <1 to 21 gigawatts of worldwide SMR capacity by 2035[13] (by which time, at the current rate of installation, an additional 2500–3000 GW of new renewable capacity will have been installed).

The slow death of fast reactors

The prospects for fast reactor technology – the most significant sub-set of 'advanced' nuclear concepts – have arguably never been bleaker. The number of operating fast reactors reached double figures in the late 1970s but has steadily fallen and will remain in single figures for the foreseeable future. Currently, just five fast reactors are operating – all of them described by the World Nuclear Association as experimental or demonstration reactors.[14]

The historical pattern strongly suggests that fast reactors are on the way out, not on a pathway to becoming "mainstream" as the World Nuclear Association claims:[14]

1976 – 7 operable fast reactors
1986 – 11
1996 – 7
2006 – 6
2019 – 5

One country after another has abandoned fast reactor technology. Nuclear physicist Thomas Cochran summarizes the history: "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."[15]

The Russian government recently clawed back US$4 billion from Rosatom's budget by postponing its already-glacial fast neutron reactor program; specifically, by deferring hold plans for what would have been the only gigawatt-scale fast neutron reactor anywhere in the world.[16] Construction of a lead-cooled fast reactor (BREST-300) was scheduled for 2016 but construction has not yet begun.[17] Plans for a SVBR-100 lead-bismuth cooled fast reactor have been abandoned.[17]

France recently abandoned plans for a demonstration fast reactor[18] and the pursuit of fast reactor technology in France is no longer a priority according to the World Nuclear Association.[19]

France's disinterest in fast reactors extends to other Generation IV concepts. French nuclear agency CEA says that "industrial development of fourth-generation reactors is not planned before the second half of this century."[18]

Other fast reactor projects have collapsed in recent years. TerraPower abandoned its plan for a prototype fast reactor in China last year due to restrictions placed on nuclear trade with China by the Trump administration[20], and requests for US government funding to support its fast reactor R&D have reportedly received a negative reception.[21]

The plan for a 'versatile test reactor' to advance fast reactor technology in the US has not yet collapsed but probably will[22], as was the case with the 'Next Generation Nuclear Plant Project' initiated in 2005 but abandoned in 2011 because of an impasse between government and industry over cost-sharing arrangements.[23]

The US and UK governments have both considered using GE Hitachi's 'PRISM' fast reactor technology to process surplus plutonium stocks – but both governments have rejected the proposal.[24] China's fast reactor program is rudimentary and underperforming; India's is troubled and underperforming.[25]

Fast reactor technology has been around since the dawn of the nuclear age and is best described as failed Generation I technology – "demonstrably failed technology" in the words of Prof. Allison Macfarlane, former chair of the US Nuclear Regulatory Commission.[26]

An existential crisis?

The situation for fast reactor technology could hardly be bleaker. The 'advanced' nuclear sector more generally faces a bleak future... and so does the conventional nuclear power industry. A sober assessment published in the *Proceedings of the National Academy of Science* last year concluded that it is most unlikely that any new large nuclear power plants will be built over the next several decades in the US; no US advanced reactor design will be commercialized before mid-century; and establishing an SMR industry would require subsidies amounting to several hundred billion dollars over the next several decades.[4]

Westinghouse neatly illustrates the nuclear industry's existential crisis. The company has designed small, medium and large-sized reactors over the past two decades:

- Its SMR program is modest and will likely be abandoned in the absence of ongoing government subsidies.
- The plan for medium-sized reactors was abandoned without a ball being bowled.[27]
- The catastrophic failure of AP1000 projects in South Carolina (abandoned after the expenditure of at least $US9 billion) and Georgia (the cost estimate for two reactors under construction has doubled to US$27–30+ billion) bankrupted Westinghouse and almost bankrupted its parent company Toshiba.

The efforts of Westinghouse and Toshiba to profit from the 'nuclear renaissance' could hardly have ended any more disastrously.

With the aging of the global reactor fleet, the International Atomic Energy Agency expects that more than 80% of nuclear power capacity to be shut down by 2050.[28] It seems increasingly unlikely that nuclear new-build will match closures over that period. And it seems most unlikely that 'advanced' nuclear will come to the rescue.

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‘The most important clean-up in Australian mining history’: Rio Tinto under scrutiny at Ranger

Author: Dave Sweeney – nuclear-free campaigner, Australian Conservation Foundation

The complex task of remediating four decades of imposed uranium operations in a World Heritage region is continuing inside Kakadu National Park in Australia’s Northern Territory. Energy Resources of Australia (ERA), majority owned by mining giant Rio Tinto, has recently released the second version of its Mine Closure Plan (MCP) outlining how it intends to rehabilitate the Ranger project, Australia’s longest running uranium mine.

Despite their clear opposition Ranger was imposed on the lands of the Mirarr Aboriginal people in the 1970s. In the decades since the mine has been a source of contamination, controversy and contest.

Under the terms of the mining license all mining and mineral processing at Ranger is required to end by January 2021. Mining ended earlier this decade and ERA is now processing stockpiled ore and increasingly turning its mind to the massive challenges involved in restoring the heavily impacted site. ERA is required to clean up Ranger to a standard where “the rehabilitated area could be incorporated into the Kakadu National Park”.

Given that Kakadu is Australia’s largest national park and is World Heritage listed for both its cultural and natural values and importance this is a very high bar and there are real concerns over how this will happen and whether it is even possible.

The general direction of the MCP is positive but, as ever, the devil is in the detail – or in this case, the lack of it. While outlining a broad rehabilitation pathway the MCP continues to defer detailed analysis and approaches to future iterations of the document over coming years. This approach is partly understandable as the works will evolve with experience and there are legitimate areas of uncertainty, but such an approach also allows considerable scope for future works to be driven primarily by corporate imperatives rather than defined environmental objectives.

The first MCP was released last year and reviewed in *Unfinished Business* (www.acf.org.au/reports), a joint report by national environment group the Australian Conservation Foundation (ACF) and Sydney University’s Sydney Environment Institute.

The report highlighted a need for increased scrutiny, broader stakeholder engagement and transparency to facilitate the best possible closure and rehabilitation outcomes at Ranger. These issues remain as unfinished business in the current version of the MCP.

A further uncertainty surrounding rehabilitation efforts at Ranger is ERA’s financial capacity. In February 2019, a new ERA feasibility study significantly increased the estimated rehabilitation costs at Ranger to around A$925 million (US$633 million). ERA has assets of around $A425 million, or less than half the amount currently understood to be needed for the clean-up. This clear funding shortfall has been described by the Mirarr as ‘a source of significant concern to the Traditional Owners’ – an understated view shared by other stakeholders.

Ranger uranium mine. *Photo by Dominic O’Brien.*

ERA has recently moved to provide some assurance over the finances needed for clean up by launching a renounceable share offer. It is planned that over three million new shares will be issued, with existing shareholders being offered the first purchase option. At the time of the launch Rio Tinto’s head of energy and minerals, Bold Baatar, stated “we take mine closure very seriously and are ensuring that ERA is able to fund the closure and rehabilitation of the Ranger Project Area”. Rio has committed take up its full entitlement and underwrite the initiative.

The new share issue will both increase Rio’s stake in ERA and raise an expected A$476 million to aid in funding rehabilitation. The initiative is being currently being challenged by Singapore-based ERA minority shareholder Richard Magides and his Zentree Investments group who, unlike Rio Tinto, are keen to continue operations at Ranger. The Mirarr Traditional Owners have spoken of the urgent need to secure a funding solution and both they and ACF have welcomed the share move as an important step in providing certainty and capacity for the complex rehabilitation and closure effort.

The challenge posed in attempting to clean up a contaminated site in a tropical landscape is profound. This is exacerbated by the Aboriginal cultural significance and global recognition and awareness of Kakadu. Veteran resource journalist Matt Stevens recently wrote in the *Australian Financial Review* that Rio “wants to make Ranger the gold standard of mining rehab” and described Ranger as “the most important clean-up in Australian mining history”.

In a single sentence he expressed the intent and the determination that has long driven the Aboriginal and environmental positioning around this work: ‘this job has to be done right’.

Rio Tinto does seem committed to repairing decades of damage at Ranger. But trust is a finite commodity and must be built, demonstrated and delivered. The Ranger rehabilitation effort remains unfinished business and Rio Tinto remains the focus of global attention and scrutiny.

Nuclear power dead and alive

Author: Jim Green – Nuclear Monitor editor

S&P Global Ratings has published a glum assessment of the prospects for nuclear power, in 'developed' countries at least. It states:[1]

"The global nuclear industry, accounting for 10% of global power generation, faces many challenges as governmental and regulatory policies have shifted toward renewables, especially after the 2011 Fukushima nuclear accident. Concerns about the safety of nuclear plants and nuclear waste storage solutions, an aging global nuclear fleet, and massively escalating costs for many new projects have added to the industry's woes.

"Several developed countries, including Germany, Belgium, Switzerland, and Spain, are planning to phase out nuclear. Others, such as South Korea, Sweden, and even France aim to reduce it. In the U.S., the continuity of nuclear plants and future life extensions are under threat from prevailing low power prices. ...

"In developed markets, we see little economic rationale for new nuclear build. Renewables are significantly cheaper and offer quicker payback on scalable investments at a time when power demand is stagnating. New nuclear construction requires massive upfront investments in complex projects with long lead times and risk of major cost overruns. Returns over nuclear assets' long useful life are exposed to fundamental uncertainties about the global energy transition, technology development, regulatory shifts, and increasingly volatile electricity markets. …

"Most of the existing reactor fleet was built in the 1970-1980s. Notwithstanding the recent uptick in nuclear construction globally after 2014, the global trend in energy investments shows a clear preference for renewables, and investments in nuclear generation are several times smaller than renewable investments. This is fundamentally because public policies do not consider nuclear to be clean energy due to safety concerns and long-term nuclear waste issues, even though it results in zero direct CO2 emissions. In addition, new nuclear reactors require vast amounts of capital investment upfront and have high execution risks, long lead times, and very long asset lives. This makes private investors cautious about investing in nuclear amid lower and increasingly volatile power prices across major markets, and rapid and continued changes in the global energy system."

Thus the S&P report expects nuclear generation to gradually decline in the US and it notes that most Western European countries plan to reduce or phase out nuclear power, South Korea has been shifting toward renewable energy sources from coal and nuclear since 2017, the road ahead for Japan's nuclear industry "is likely to be long and challenging, and so on.

Small modular reactors are quickly dismissed: "they are still far too expensive and less scalable than renewables, and do not address fundamental nuclear safety and nuclear waste issues."

The report notes that even assuming investment costs come down significantly to US$4,500/kW, nuclear power would cost around US$100/MWh and its economic competitiveness would be "clearly questionable". The assumed $4,500/kW construction cost is "much lower than actual first-in-kind projects that have experienced large cost overruns" (and much lower than the US$6,900 – $12,200 estimate in the latest Lazard report.[2])

Dead and/or alive?

Despite the glum assessment outlined above, the S&P report predicts that nuclear power output is set to increase marginally over the next two decades. Questionable assumptions leading to that conclusion include the following.

Reactor lifespan extensions

Lifespan extension licenses are given undue weight in the S&P report. The escalating cost of continuing to operate aging reactors, relative to more competitive energy sources, isn't given due weight. The risks of continuing to operate aging reactors are ignored altogether (as are the connections between nuclear power and weapons).

The S&P report asserts that "a too fast nuclear phaseout" would have a "huge impact on CO2 emissions". Only if you assume that gas and coal are the replacement energy sources, and ignore renewables and energy efficiency altogether – which is what the report does.

Emerging economies

The S&P report anticipates nuclear decline across developed countries but growth in 'emerging economies', with China taking the lead. China will need to "accelerate" the construction of new nuclear power plants to achieve its ambitious 2020 target of having 58 gigawatts (GW) of nuclear capacity in operation (from 45 GW in 2019) and 30 GW under construction (from 11.2 GW as of Nov. 2019[3]).

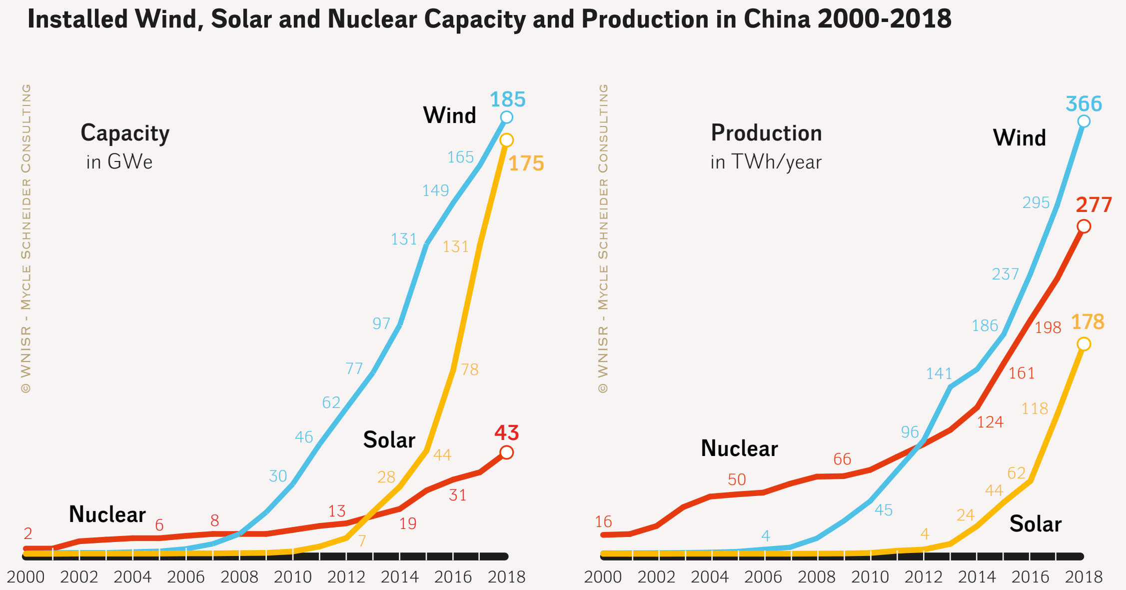
But no credible acceleration could possibly see China meet its 2020 targets. Recent years have seen a sharp deceleration – just one reactor construction start since December 2016. A World Nuclear Industry Status Report briefing states:[4]

"China National Nuclear Corporation (CNNC), on 16 October 2019, announced the construction start of Zhangzhou-1, a Hualong or HPR-1000 design. ... This is the first new construction start for the Hualong design reactor – and the first construction start of any

commercial reactor – since 23 December 2016 ... With the latest construction start, a total of 11 reactors are now under construction in China. This is significantly below the figure of 16 in 2017, and of 20 in 2016. This new-build decline is a clear demonstration of the slowdown of the Chinese nuclear power program. With currently 45.5 GW in operation and 10 GW under construction, China will be far from achieving its 5-year target of 58 GW operating and 30 GW under construction as of 2020."

According to the S&P report, China's nuclear program benefits from an economic learning curve effect, a complete supply chain, and "good project management that reduces execution risks". But the economic case for nuclear clearly isn't compelling – hence the go-slow in recent years. Moreover, renewables have expanded far more rapidly – wind already generates more power than nuclear and solar is catching up fast.

And there is a trade-off between safety and economics – a trade-off ignored in the S&P report. Accidents – large and small – are all the more likely because of China's inadequate nuclear safety standards, inadequate regulation, lack of transparency, repression of whistleblowers, world's worst insurance and liability arrangements, security risks, and widespread corruption.[6]



Source: World Nuclear Industry Status Report, 2019

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Yeelirrie Solidarity Camp 2019

Author: K-A Garlick – nuclear-free campaigner with the Conservation Council of Western Australia.

The launch of the first Yeelirrie Solidarity Camp was a massive success with over 30 campaigners from across Australia and Aotearoa / New Zealand participating in the one-week event at Yeelirrie to support Traditional Owners who oppose uranium mining in Western Australia (WA).

The Solidarity Camp replaced this year's Walking for Country and was launched at the end of September as a camp-out on Tjiwarl country, better known as the Goldfields region of WA near the site of the proposed uranium mine.

Over thirty interested and passionate people listened, learned and showed their support to the people of both Kalgoorlie and Leonora in their fight to stop uranium mining on their country. For a week we travelled part of the proposed "nuclear freeway" between the Mulga Rock uranium project, Kalgoorlie and the proposed Yeelirrie uranium project.

The first night we spent in Kalgoorlie with our good friends and local hosts at the Wongathu Birni Aboriginal Centre. We were welcomed by Anangu women Debbie Carmody and her sister Libby Carmody from Tjulma Pulka Media Aboriginal Corporation. Debbie and Libby have joined many walks all over the world with Footprints for Peace and reconnected this night with many of the walkers. They have been standing up strong against the proposed Mulga Rock uranium project.

Also joining us at Kalgoorlie was Kokatha woman Sue Coleman-Haseldine from Ceduna (South Australia) and her sister Sue Thiselton, both long-time activists about the suffering from the Maralinga bomb tests and advocating for a future without nuclear weapons. They joined to stand with the Tjiwarl aunties to stop the threat of uranium mining on country.

The following day we travelled a further 430 kms to Sir Samuel to stay with Tjiwarl woman Vicki Abdullah and family at the Bellevue Gold Camp that has been negotiated with some of the Traditional Owners of the area. It was an interesting and insightful stay, raising many questions for the group.

A short drive the following day along the red earth unsealed roads towards Yeelirrie had us arriving before lunch to set up camp for four nights. We had a beautiful welcome to country by Vicky and that evening she shared her story as we sat around the fire.

This country has become very familiar to many of us who have returned year after year for nearly 10 years to show our opposition to uranium mining in WA. For many of us it is a welcome, familiar feeling in which we feel at ease amongst the beautiful mulga trees, spinifex, red earth and big blue skies.

Yeelirrie station

The following day we arose early to walk to the gates of the Yeelirrie station. There are many conversations as we walk behind the Aboriginal flag leading the walkers to the gates.

A campaign update was given at the gates about the proposed Yeelirrie uranium project, and a short campaign history covering Walking for Country events, actions in Perth and elsewhere, and the legal battle – three Tjiwarl aunties, Shirley, Lizzie Wonyabong and Vicki Abdullah fought hard for over 2.5 years to save their country in a legal battle against the Canadian company Cameco and the WA government. They are true warriors.

The afternoon was filled with an excellent nuclear free snapshot from Aunty Sue, Gem Romuld from the International Campaign to Abolish Nuclear Weapons (ICAN), and Mara Bonacci, SA nuclear-free campaigner with Friends of the Earth.

That evening around the camp fire, we listened to the incredible personal story of Aunty Sue Coleman-Haseldine. The story of people still suffering from atomic bomb testing in SA more than half a century ago. It was a powerful reminder of this deadly and toxic industry that we are trying to stop. Aunty Sue was born just before her family's desert lands to the north were bombed by the deadliest weapon we know by the British government. She told of us of the invisible killer that she had

Yeelirrie Solidarity Camp 2019

experienced through grand-daughters' thyroid removals and the still-born jelly babies born in her family.

"Anything to do with uranium mining and nuclear there is no winners, everybody loses. You can never feel guilty about what happen in the past, you can't turn back time but you can work together for a better future," she said.

A STOP sign sits at Yeelirrie Station. The women here are locked out of their own country. Some miners and governments are putting these stop signs up here. These companies and governments have only come in lately – these people have been here forever and they don't have the right to go beyond the signs without someone saying so.

We headed out to good allies and local station holders, Colin and Marilyn from Youono Downs. Marilyn had invited all of us to come over and take showers and cool off in the oasis of their station. We settled in to listen to Marilyn and Colin's concerns about the uranium mine project. As they have been fighting for many years, they also had many stories to share!

Back at camp and surrounding the fire, we heard the great stories from Bilbo Taylor with his incredible experience of remote blockading. From stories to strategies we listened to the dangers, the rewards, the creative and fun ways of remote blockading. For many years, Uncle Kev, Bilbo and others kept a constant vigil on BHP's Olympic Dam uranium mine in SA.

Campaign planning

On our last full day at Yeelirrie, we revisited the core themes of the camp, and broke off into smaller working groups to discuss campaign options. We came away with six working groups for ongoing campaign work – communication, outreach, creatives, fundraising, resources and spokes group.

We have a richness in this campaign that is from the connection to people and connection to this country. We have built a solid base and this will continue to slowly build should we need to fight by blockading. People are preparing themselves for the long fight. Our three core themes for the camp – a 10-year campaign strategy, Yeelirrie blockade, and active campaigning now – were all addressed during the week and clear outcomes achieved.

Red earth deep in our pores, the landscape etched in our minds, relationships deepened, we leave feeling satisfied to stand with the Tjiwarl women and community that tirelessly fight to stop uranium mining on their country. We stand as one, we stand together.

See the video at https://vimeo.com/366701061

A longer version of this article, with lots of photos, is posted at www.ccwa.org.au/yeelirrie_solidarity_camp_2019

Tjiwarl women win conservation award for uranium mine campaign

"Over the decades they have seen off at least three mining companies, including BHP, and in the process they have given strength and courage to their own community and many others."

Three Tjiwarl women, Shirley Wonyabong, Elizabeth Wonyabong and Vicki Abdullah, have been awarded the Australian Conservation Foundation's 2019 Peter Rawlinson Award for their decades-long campaign to protect their country and culture from a proposed uranium mine at Yeelirrie in outback Western Australia.

"Shirley, Elizabeth and Vicki, along with other Tjiwarl people, have spoken up for their country and culture around campfires, in politicians' offices, on the streets of Perth and in Western Australia's highest court, all the while looking after their grandchildren and each other," said ACF's Chief Executive Officer, Kelly O'Shanassy.

"Every year for the last eight years, these women have taken people from all over the world through their country on a one-month walking tour. In this way, hundreds have seen their land. Over the decades they have seen off at least three mining companies, including BHP, and in the process they have given strength and courage to their own community and many others."

The latest company with ambitions to mine uranium at Yeelirrie is Canada's Cameco, which hopes to dig a nine-kilometre open mine pit and destroy 2,400 hectares of native vegetation. Cameco's proposed mine would use nine million litres of water a day and generate 36 million tonnes of mine waste that would remain radioactive for thousands of years.

Shirley Wonyabong, Elizabeth Wonyabong, and Vicky Abdullah.

The WA Environmental Protection Authority (EPA) rejected Cameco's proposal because it was almost certain to wipe out several species, including rare stygofauna (tiny subterranean creatures that live in the groundwater) and the entire western population of a rare saltbush, and harm other wildlife like the Malleefowl, Princess parrot and Greater bilby.

But state and federal authorities went against the EPA's advice and approved the mine.

Shirley, Elizabeth and Vicki took the matter to court – eventually to the Supreme Court of Appeals – which dismissed their case, confirming conservationists' fears that an Environment Minister can legally approve a mine knowing it would lead to the extinction of multiple species.

What the World Nuclear Waste Report doesn't say about the UK

The first-ever World Nuclear Waste Report (worldnuclearwastereport.org) is a mighty achievement and hopefully future reports will build on the foundations. As a first-of-a-kind report, inevitably there are limitations and omissions (and possibly delays and cost overruns!). Pete Roche expands on the WNWR's section on the UK.

The World Nuclear Waste Report[1], published earlier this year doesn't quite give readers a view of the full horror of the radioactive waste mess the UK has got itself into.

Waste from new reactors

The report says the independent Committee on Radioactive Waste Management (CoRWM) reported in 2006 in favour of Deep Geological Disposal (DGD) for all higher activity waste, but doesn't mention that CoRWM's 2006 report emphasised that its recommendations were directed to "existing and committed waste arisings … New Build wastes would extend the timescales for implementation, possibly for very long, but essentially unknowable, future periods. Further, the political and ethical issues raised by the creation of more wastes are quite different from those relating to committed – and therefore unavoidable – wastes."[2]

In September 2007 CoRWM re-iterated the point saying: "To justify creating new spent fuel from an ethical point of view, there must be a management solution that is ethically sound, not just least bad. … In short, a solution that is ethically acceptable for dealing with existing spent fuel is not necessarily a solution that would be ethically acceptable for dealing with new or changed materials."[3]

Sellafield's high-level liquid waste

The report says closure of the Magnox stations and the poor and deteriorating state of Sellafield made it clear by the early 2000s that a more coherent policy and higher expenditures were needed to manage waste in the short- and medium-term. The establishment of setting up the Nuclear Decommissioning Authority (NDA) in 2005 was a recognition that Sellafield was the most problematic UK site, containing a huge range of ex-military and ex civilian buildings and wastes including four so-called Legacy Ponds and Silos, all representing major hazards, as well as being home to virtually all UK spent fuel. But there is no specific mention of the extreme concerns expressed about the liquid High Level Waste tanks, especially after the 2001 terrorist attacks in New York and Washington.

The intensely radioactive liquids known as Highly Active Liquors (HAL) which result from reprocessing spent fuel generate their own heat, so must be stored at Sellafield in special cooling tanks to prevent the waste from boiling. The consequences of a prolonged cooling failure could be 'very severe' leading to boiling after 12 hours, and to the tanks drying out after three days with radioactivity escaping and contaminating the surrounding

Corroded pipes at Sellafield. Discussed in The Ecologist, 27 Oct 2014, Leaked Sellafield photos reveal 'massive radioactive release' threat

environment. Consequently, the HLW facility at Sellafield is probably one of the most dangerous nuclear facilities in the world with the potential to at least force the evacuation of much of northern England and southern Scotland, and cause long lasting contamination well beyond the UK.[4]

The Highly Active Liquor Evaporation and Storage (HALES) area at Sellafield consists of four evaporators A, B, C, the recently commissioned D[5], and a number of High Activity Storage Tanks (HASTs). There are 21 tanks, some dating back to the 1950's[6], but the number in use has been reducing since 2009 with only around half in use by 2013.[7]

In the year 2000, the Nuclear Installations Inspectorate (NII) (now part of the Office for Nuclear Regulation – ONR) warned that the High-Level Liquid Waste storage tanks at Sellafield needed to be emptied and the waste solidified "as soon as reasonably practicable", reaching a buffer level by 2015. Any shortfall, it said, would be "publicly unacceptable".[8] In January 2001, the NII issued the Sellafield operator (at the time British Nuclear Fuels Ltd BNFL) with a legal requirement to reduce the level of High-Level Liquid Waste down from approximately 1600m3 to a residual or buffer stock of 200m3by 2015.[9]

Following the 9/11 terrorist attacks a review was undertaken by the Parliamentary Office of Science and Technology (POST) of the impact of similar attacks on vulnerable UK facilities. It found that a terrorist attack on the tanks could require the evacuation of an area between Glasgow and Liverpool, and cause around 2 million fatalities.[10] The Massachusetts-based Institute for Resource and Security Studies (IRSS) reported that highly radioactive liquid stored in tanks contained around 2,400 kilograms (kg) of Caesium-137 compared with the 30 kg released during the Chernobyl accident.[11]

In 2011 the ONR decided to increase the permitted level of HAL stocks to almost three times the limits defined under the earlier legal requirement.[12] This increase to the 'buffer level' was to provide Sellafield with "the flexibility to accelerate the hazard reduction". Part of the explanation given for this was that the original legal requirement was set at a time when reprocessing was expected to have been completed by about 2015, at which time a minimal working "buffer stock" level would have been reached. But reprocessing operations had been plagued with problems. THORP is now closed and the Magnox Reprocessing Plant is expected to close in 2020. The 2011 ONR recommendation was that the Steady-State Specification should be set at 5,500 tonnes uranium (teU).

The Chief Nuclear Inspector reported in October 2019 that stocks of Highly Active Liquor at Sellafield currently amount to around 5,750teU. According to the Inspector stock levels have remained steady for the last few years "due to a number of operational issues, but it is anticipated that HAL stock reduction will now continue".[13] 5,750teU would be equivalent to around 484 m3 – more than double the buffer stock originally expected to be achieved in 2015 by the NII. (If 19,000 teU is equal to 1,600m3, 5,750 teU = 484m3.)

Scottish policy

The World Nuclear Waste Report mentions briefly that "Scotland's policy is different from that of the rest of the UK, and envisages near-surface disposal of all nuclear waste within its borders". The Scottish Government's policy, in fact, only refers to Higher Activity Waste. It says that the long-term management of higher activity radioactive waste should be in near-surface facilities. Facilities should be located as near to the site where the waste is produced as possible. The Scottish Government does not support deep geological disposal of radioactive waste.[14]

However, since spent fuel is not classified as waste, spent fuel from Scotland's remaining operating reactors is still transported to Sellafield. Nor does the policy apply to LLW or VLLW. Scotland does not have a landfill site for VLLW, or an LLW repository outside of Dounreay, so still sends lower level waste to the Low Level Waste Repository at Drigg in Cumbria and English landfill sites at Clifton Marsh in Lancashire and Augean in Northamptonshire. It also continues to send contaminated metal for decontamination and so-called recycling to the Cycliffe plant at Lillyhall in Cumbria.

Dounreay

Dounreay is hardly covered in the report, although the fact that it is a site for LLW disposal is mentioned, despite it being the site of some of our worst horror stories. Dounreay was the UK's centre of fast reactor research and development between 1955 and 1994 and is now described as Scotland's largest nuclear clean-up and demolition project.

The Dounreay Fast Reactor (DFR) first achieved criticality in 1958, and operated until 1977. Most of the breeder elements were removed soon after, but almost 1,000 were found to be swollen and jammed in place. They were left in place until remotely-operated tools could be developed.[15] Recovering the jammed elements began forty years after the reactor closed, and by 2019 half of them were still in place.[16] This spent fuel is being transported to Sellafield for reprocessing in the Magnox fuel reprocessing plant but not all of it will arrive before the plant closes in 2020, so arrangements are being made to dry store the remainder at Sellafield.

The Prototype Fast Reactor (PFR) opened in 1974 and closed in 1994. The site also housed a fast reactor reprocessing plant, as well as a research reactor reprocessing plant. Overseas research reactor spent fuel was imported for reprocessing up until 1974 when it stopped because foreign customers were unwilling to take their waste back. Then in 1992 Dounreay re-entered the research reactor spent fuel reprocessing business with spent research reactor fuel imported, mainly from Germany until it was announced in 1998 that Dounreay would not take on any new contracts. Dounreay was also site of a materials test reactor which operated between 1958 and 1969. The Vulcan submarine reactor test facility is also at Dounreay with one reactor in care and maintenance and another in the process of being defueled and spent fuel being dispatched to Sellafield.

In 1958 the Scottish Office authorised use of an underground shaft – built to remove spoil during construction of a sub-sea effluent discharge tunnel – as a disposal facility for intermediate level radioactive waste. More than 11,000 disposals took place between 1959 until 1977, when a chemical explosion occurred and the practice ceased. Decommissioning the 65-metre deep shaft is a major challenge. A second facility, the intermediate-level waste silo, also needs to be emptied. A concrete-lined box built just beneath the surface, it was used to dispose of waste between 1971 and 1998. Work to retrieve waste from the shaft and silo isn't expected to get under way until around 2023. Preparatory and construction work have to be carried out before the waste can be removed.[17]

Another major problem at Dounreay is the appearance of radioactive particles in the environment. These small fragments of irradiated nuclear fuel have been found on the seabed off Dounreay, on the Dounreay foreshore and on Sandside Beach west of Dounreay, which is open to the public. A fishing ban prohibits the removal of fish, crustaceans and molluscs in an area of 2km (1.2 mile) radius centred on the disused Dounreay discharge point near where the highest density of particles has been detected.[18] It will be around 200 years, before the activities of the larger particles, have decayed sufficiently that they can no longer be considered a potential hazard. Particles will keep polluting public beaches for decades to come, and the environment will never be completely cleaned up. Despite assurances that the risk is low of a member of the public coming into contact with a particle which is a serious hazard to health, it is uncertain that this will continue to be the case. Since 1983 almost 500 radioactive particles have been found including more than 200 on the publicly accessible Sandside beach.[19]

In 2015 new low-level waste vaults at Dounreay started to accept waste.[20] This is the only UK low-level waste 'disposal' facility other than the low-level waste repository at Drigg near Sellafield. Previously low-level waste generated at Dounreay had been dumped in a rather haphazard fashion in the low-level waste pits. The current plan is eventually to retrieve the waste from these pits, repackage it and then place it in the new vaults. However, the Scottish Environment Protection Agency (SEPA) has told Dounreay that it has been "non-compliant with regard to its obligation not to allow radioactive substance to contaminate the groundwater near the pits". This may force Dounreay to remove the waste from the pits sooner than originally planned.

Radioactive water is leaking from a nuclear waste storage building as big as 132 double-decker buses at Sellafield. Sellafield Ltd said there is no risk to staff nor the wider community as the water, which covers the solid radioactive waste in the silo, will remain in the ground "for some time". The leak is believed to be originating from the six older compartments of the Magnox Swarf Storage Silo, which has 22 compartments in total. However, it is not known how much water has been lost so far. The majority of the radioactive material stored there is fuel cladding, which Sellafield says has an intermediate level of radioactivity.[21]

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