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Small Modular Nuclear Reactors, the UK’s long-term nuclear strategy and Ireland’s future energy mix debate.

i. Background to Briefing

This briefing has been developed by the NFLA Secretary to consider the potential and proposed development of small modular nuclear reactors in the UK and, possibly Republic of Ireland. These developments have been the subject of a recent review by the UK Parliamentary Energy and Climate Change Select Committee. The UK Government has also instructed the National Nuclear Laboratory to investigate the potential of SMRs and the obstacles that need to be overcome to successfully develop them.

In the Republic of Ireland, SMRs have been put forward as one of the potential answers to Ireland’s future low-carbon energy mix. The Irish Government has included discussion of them in its 2014 Green Paper on Energy Paper, and has confirmed SMRs will be considered in a White Paper expected to be published later this year. This briefing considers whether SMRs are a realistic prospect in the short-term to medium-term, particularly given the problems besetting much larger developments, such as at Hinkley Point C.

1. Introduction

The UK Government’s long-term nuclear strategy envisages making the UK a ‘top table’ nuclear nation, working in international partnerships leading the direction of future technology advances across the nuclear fuel cycle and being a key partner in commercialising new reactor-types such as Small Modular Reactors (SMR) worldwide. (1) A nuclear research and development programme has been sketched out which would give the UK the option of promoting a high-nuclear scenario for the country with up to 75GW of nuclear capacity in 2050 providing 86% of the UK's electricity supply. (2) This would require an eye watering 30GW of new capacity to be built between 2030 and 2040 and another 30GW between 2040 and 2050, and newer fission technologies such as small modular reactors (SMRs) or Generation IV (mainly fast) reactors. Spent fuel reprocessing, fusion reactors and alternative fuel cycles (such as thorium) might also be needed. While to most commentators this would sound like a nuclear fantasy, unfortunately the UK Coalition Government is not looking seriously enough at alternative non-nuclear energy strategies. (3)

In the Irish Republic a Green Paper on Energy, published for consultation in summer 2014, asked whether it might now be time to consider introducing a small nuclear reactor to replace the Moneypoint coal-fired power station, and to test public acceptance of nuclear power. (4)

2. What is a small modular nuclear reactor?

The International Atomic Energy Agency (IAEA) defines a small reactor as one with a capacity under 300MW, compared with the two 1,600MW reactors planned for Hinkley Point C in Somerset

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or the two 660MW reactors at Hinkley Point B.

Small Modular Reactors (SMRs), which have been receiving a lot of attention in the USA, are promoted as a possible way of introducing nuclear generating capacity in smaller and more affordable increments. The idea behind SMRs is that by mass-producing major components as standard modules in factories, and shipping the modules to sites for assembly rather than having each reactor custom-designed and built, substantial cost savings can be realised.

A recent House of Commons Energy and Climate Change Committee investigation into small reactors looked at SMRs, but also PRISM reactors which are 311MW sodium-cooled fast reactors being promoted as a way of using up the plutonium stockpile at Sellafield. In additions the Committee looked at reactors fuelled by thorium rather than uranium, which can be of any size.

3. Small Modular Reactors (SMRs)

The American Union of Concerned Scientists (UCS) say small isn't necessarily beautiful. (5) Economies of scale dictate that, all other things being equal, larger reactors will generate cheaper power. SMR proponents suggest that mass production of modular reactors could offset economies of scale, but a 2011 study concluded that SMRs would still be more expensive per kWh than current reactors. (6) Dr. Mark Cooper, senior fellow for economic analysis at the Vermont Law School's Institute for Energy and the Environment agrees with UCS that SMRs are likely to have higher costs per unit of output than conventional reactors. (7) Even if SMRs could eventually be more cost-effective than larger reactors due to mass production, this advantage would only come into play if large numbers of SMRs were ordered. But utilities are unlikely to order an SMR until they are seen to produce competitively priced electricity. This 'Catch-22' conundrum suggests the technology will require significant government financial help to get off the ground.

The Washington-based Institute for Energy and Environmental Research (IEER) says mass production could create new reliability vulnerabilities – if one reactor is discovered to have a fault, all other reactors manufactured in the same facility are likely to have the same fault, so all would have to be taken off-line at the same time. Millions of cars, presumably made to high quality control standards, for instance, are routinely recalled. Additionally IEER has serious concerns in relation to both safety and proliferation. (8) By spreading SMRs around the globe it is likely to increase the proliferation risk because safeguarding spent fuel from numerous small reactors would be a much more complex task than safeguarding fewer large reactors. (9)

4. Safety of SMRs

Proponents of SMRs also claim that smaller reactors are inherently less dangerous than larger ones. For instance, with smaller cores proponents say they are easier to keep from overheating. But the real concern has to be that the pressure to keep costs down will lead to compromises on safety. Indeed the economic case for SMRs depends in part on the assumption that nuclear regulators can be convinced to diluted standards in certain safety and security areas. Far from increasing design and operational safety standards, proponents of SMRs claim small modular reactors will be so much safer than large reactors that they will not need to meet the same safety standards as large reactors, arguing that they need far fewer operators and security officers, and that they can have disproportionately smaller and weaker containment buildings. SMR advocates also claim that they are so safe they can be located close to densely populated areas with considerably smaller emergency planning zones. (10)

5. The future for SMRs does not look promising

The singular problem so far for SMRs is that there simply is no current market for them. It is difficult to find business for a technology that has not been developed, licensed or proven. The US Nuclear Regulatory Commission does not even have requirements or guidelines in place to license SMRs. For the nuclear industry it costs a lot of money to be innovative. Building a supply chain from scratch, with few investors willing to bank on an unknown technology or customers willing to buy is virtually impossible. (11)

Of the four companies looking at SMR designs in the US, the Babcock & Wilcox Company (B&W) with their 180MW mPower reactor was the first company to receive cost-sharing funds from the U.S. Department of Energy (USDOE), but has now had to cut 200 staff from its workforce, and slashed spending from $60 to $80 million per year to less than $15 million, as well as restructuring its management. It is currently trying to sell up to 70% of the business (B&W plans to keep a 20 percent share and Bechtel will still own 10 percent), but it does not seem at present that anyone is willing to buy this share. As of November 2013, B&W had already invested more than $360 million in the Tennessee Valley Authority's Clinch River site in Tennessee, which was to be home to two mPower SMRs.

Westinghouse, which was once considered a certainty to pass the second round of USDOE funding, was not only passed over for consideration, but eventually decided to pass up the opportunity to develop its 225-MW SMR. This was because it wants to focus on the global market for its AP1000 reactor.

The Holtech SMR 160MW reactor lost out in the battle for USDOE funding to NuScale Power LLC, which appears to be the only company staying in the race. NuScale, which is majority-owned by Fluor and supported by Rolls Royce, just completed negotiations with the USDOE for its cost-sharing program, and is opening a regional operations centre in Charlotte. The company has signed an agreement with the USDOE to build a NuScale Power SMR demonstration unit at the Savannah River Site. The USDOE said it would provide $217 million in matching funds over five years to the 45MW NuScale reactor. Yet NuScale only gets the federal funds if it can match them with money from private investors, who so far have been wary of the technology. The company hopes to submit its design certification in the latter half of 2016. And it plans to have its first plant operating commercially by 2023. (12)

It would signal significant progress for the SMR market, if NuScale could attract private capital, resulting in not having to rely on government subsidies, but as KPMG points out investors will want to see SMR learning-curve effects. "*Decreased cost comes from production of multiple units over time, yet such production requires investment in the first place. So it's not surprising that, in the absence of commercial orders, Westinghouse and Babcock & Wilcox have slowed SMR development.*"

Arjun Makhijani of IEER says: "*There may be a chance that there are venture capital entities who might take a chance on SMRs, but I would doubt that any sensible investor would fund an SMR project. The chance of a return on the investment is not that high. It's still not certain that SMRs will solve the problems that they are meant to, in comparison with large conventional plants."* (13)

The Executive Director of the Bulletin of Atomic Scientists, Kennette Benedict says SMRs do not "*offer satisfactory solutions to the most pressing problems of nuclear energy: high cost, safety, and weapons proliferation*." (14)

Dr. Mark Cooper expresses perhaps the most serious problem with small reactors in terms of developing an effective climate and energy policy. He says that large-scale development of "small modular reactors" (SMRs) in the USA would cost around $90 billion – an amount that likely would be diverted from the development of much more cost- and climate-effective renewable energy solutions. It would also undermine the effort needed to create the physical and institutional infrastructure to support the emerging electricity systems based on renewables, distributed generation and intensive system and demand management. Whether the reactor is large or small, nuclear power is among the least attractive climate change policy options because it is too costly, too slow, and too uncertain. (15)

7. PRISM Reactors

The U.S. Corporation GE Hitachi (GEH) is promoting a reactor design called the PRISM (Power Reactor Innovative Small Modular) that its chief consulting engineer and fast-breeder guru, Eric Loewen, says is a safe and secure way to power the world using “yesterday's” nuclear waste – in his mind the plutonium which has not been officially classified as waste in the UK. The Nuclear Decommissioning Authority (NDA) has declared PRISM to be a “credible option” for managing the UK’s plutonium stockpile. (16)

PRISM is the latest manifestation of the much-hyped but non-existent 'integral fast reactors' (IFR). GEH says it offers PRISMs on the world market - but there are to date no takers, so none have been built. (17) It would require converting the plutonium oxide powder at Sellafield into a metal alloy, with uranium and zirconium. This would be a large-scale industrial activity on its own that would create "*a likely large amount of plutonium contaminated salt waste*", according to Adrian Simper of the NDA. Once prepared for the reactor, plutonium metal would be even more vulnerable to theft for making nuclear weapons or cruder devices than the plutonium oxide. (18) This view is shared by the Union of Concerned Scientists in the U.S., which argues that plutonium liberated from spent fuel in preparation for recycling "*would be dangerously vulnerable to theft or misuse*."

Arjun Makhijani says recommending the use of sodium cooled-fast neutron reactors to denature plutonium reveals a technological optimism that is disconnected from the facts. Some of them have indeed operated well. But others, including the most recent — Superphénix in France and Monju in Japan — have miserable records. Roughly $100 billion has already been spent worldwide to try and commercialize these reactors — to no avail. Liquid sodium has proven to be a problem coolant. Even small leaks of a type that would cause a mere hiccup in a light-water reactor would result in shutdowns for years in sodium-cooled reactors. That is because sodium burns on contact with air and explodes on contact with water. The PRISM reactor has a secondary cooling loop in which the fluid on one side is sodium; on the other it is water, which turns to steam to drive a turbine. (19) Nuclear engineer Dave Lochbaum from UCS says: *"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."* (20)

8. Thorium Reactors

The UK is actively involved in research to develop thorium reactors and the thorium fuel cycle through organisations such as the National Nuclear Laboratory (NNL) and its partners, as well as the UK Research Councils' Energy Programme. The Nuclear Energy Research and Development Roadmap (21) concluded that further analysis and fuel cycle modelling will be necessary to understand the implications on waste management and disposal of using thorium fuels.

There is a modern mythology that suggests that thorium might be able to replace uranium and deliver a safer and cheaper nuclear reactor with more abundant fuel. Thorium technology is in principal based on nuclear fission and therefore keeps fission's inherent problems. While it partially addresses some of the downsides of current commercial reactors based on uranium (plutonium) fuel, such as limited reserves of uranium and unwanted production of plutonium and transuranic isotopes, it still has significant issues related to fuel mining and fabrication, reactor safety, production of dangerous waste, and the hazards of the proliferation of nuclear weapons. (22)

The UCS point out that thorium cannot be used by itself to sustain a nuclear chain reaction: it must be used together with a fissile material such as enriched uranium, uranium-233, or plutonium. The U.S. Department of Energy has concluded after a review that “*the choice between uranium-based fuel and thorium-based fuel is seen basically as one of preference, with no fundamental difference in addressing the nuclear power issues* [of waste management, proliferation risk, safety, security, economics, and sustainability].” (23)

UCS continues some people believe that liquid fluoride thorium reactors, which would use a high-temperature liquid fuel made of molten salt, would be significantly safer than current-generation reactors. However, such reactors have major flaws. There are serious safety issues associated with the retention of fission products in the fuel, and it is not clear these problems can be effectively resolved. Such reactors also present proliferation and nuclear terrorism risks because they involve the continuous separation, or “reprocessing,” of the fuel to remove fission products and to efficiently produce U-233, which is a nuclear weapon-usable material. Moreover, disposal of the used fuel has turned out to be a major challenge.

Bob Alvarez, who served as senior policy adviser to the US Energy Department's Secretary and the Deputy Assistant Secretary for National Security and the Environment from 1993 to 1999, says the US has lost track of 96 kilograms of uranium 233, and is in a legal battle with the State of Nevada over the proposed dumping of nearly a ton of left-over fissile materials in a government landfill site, in apparent violation of international standards. The US has tried to develop thorium as an energy source for some 50 years and is still struggling to deal with the legacy of those attempts. In addition to the billions of dollars it has spent, mostly fruitlessly, to develop thorium fuels, the US government will have to spend billions more, at numerous federal nuclear sites, to deal with the wastes produced by those efforts. Although thorium atoms do not split, researchers in the 1940s found that they will absorb neutrons when irradiated. After that a small fraction of the thorium then transmutes into a fissionable material - uranium 233 - that does undergo fission and can therefore be used in a reactor or bomb. (24)

Even the UK Department of Energy and Climate Change commissioned a report which concluded in 2012 that the claims by thorium proponents who say that the radioactive chemical element makes it impossible to build a bomb from nuclear waste, leaves less hazardous waste than uranium reactors, and that it runs more efficiently, are "*overstated*". (25)

9. House of Commons Energy and Climate Change Committee findings on SMRs

Having failed to make much progress in the US, small reactors vendors were given an opportunity to present their case in the UK when the House of Commons Energy and Climate Change Committee announced an inquiry into small reactors in March 2014. (26) The Committee took evidence from NuScale and Babcock & Wilcox, but also from GE Hitachi on PRISM reactors. The committee published its report on 17th December 2014. (27)

The MPs want the UK Government to work with industry to better understand the economics of Small Modular Reactors (SMRs) and set out a clear explanation of the conditions under which they might become cost competitive in the UK. The report says it will be important to understand the future cost comparison with large-scale nuclear reactors as well as the comparison with other small-scale energy generation or demand management.

Deployment of SMRs is likely to be achieved through sharing the costs between the public and private sector and the Committee would like to see the Government steering industry towards deploying a demonstrator SMR in the UK. Government should help to establish the right conditions for investment in SMRs, for example through supporting the regulator to bring forward approvals in the UK, and by setting out a clear view of siting options. It might take six years to give regulatory approval (including a site-specific licence) for a small modular reactor. The Committee is calling on DECC to ensure that the Office for Nuclear Regulation is adequately resourced to support SMR developers in the early stages of preparing their designs for approval. (28)

Speaking at the Nuclear New Build conference, shadow energy minister Tom Greatrex warned the government that “*no one, including the Chancellor as he drafts his Autumn Statement, should be fooled into thinking that small nuclear reactors are somehow the answer to all our energy needs*.” But he did concede that there are “*many opportunities” for small and medium scale reactor technologies”*. (29)

Meanwhile the energy minister for the Republic of Ireland, Alex White has said that nuclear power ought to be considered in a debate on the country's future energy needs. A Green Paper on Energy was published for consultation last summer. This asked whether it might now be time to consider the potential economic and technical implications, of introducing a small nuclear reactor to replace the Moneypoint coal-fired power station and to test public acceptance of nuclear generation located on the island of Ireland. (30) At the moment nuclear power is banned in Ireland.

White told the Irish Independent in an interview published on 31 December 2014 (31) "*We have a dependence on damaging carbon-based energy sources which are effectively destroying the planet. You cannot preside over a full debate by excluding anything*." (32) The Department of Communications, Energy and Natural Resources is currently working on a long-term energy strategy which will set out the role for conventional power generation from oil and gas; renewables including wind and energy; along with nuclear and other energy sources. This White Paper will be a definitive statement on what the energy needs are for the future of Ireland, and this will be published in the summer of 2015. (33)

10. UK Government Response

On 14th July 2014 the UK's outgoing Minister for Business and Energy, Michael Fallon, told Parliament that the Government was "*awaiting the outcome of a feasibility study, led by the National Nuclear Laboratory [NNL] with the support of a consortium formed from industry. The study will make initial recommendations on the economic, technical and commercial case for SMRs, and will inform the evidence base for any further development or action."* (34)

The NNL feasibility study was published in December 2014. It concluded that the UK has an opportunity "*to regain technology leadership*" in SMRs. It said there is a very significant market for SMRs in places where large reactors would be unsuitable and calculates the size of the market to be approximately 65-85 GW of new capacity by 2035, valued at £250-£400 billion, with demand in the UK of around 7 GW by then. NNL claims that "first-of-a-kind" SMRs could be cost comparable with conventional nuclear build, with the potential to become more cost competitive as more are built. But further evidence is required to make a policy decision or for business to make an investment. Paul Howarth, NNL managing director, said the feasibility report is "*an important step on the way towards recognizing the role which SMR designs can play and helping to capitalize on the opportunities offered*." (35)

In March 2015 the UK Government responded to the Select Committee saying that it recognised the long-term potential of SMRs as an additional source of generation, which is why it commissioned the SMR feasibility study from the National Nuclear Laboratory. (36) That study recommended a more in-depth analysis to establish the robust evidence base needed to enable a policy decision on SMRs and help Government decide whether it wants to pursue a UK SMR programme. This further analysis has now been commissioned. It will look at what is needed to bring SMRs to market, and further financial analysis to clarify the economic case.

The Select Committee said it was surprised to learn that it might take six years to give regulatory approval for an SMR (including a site-specific licence). The Government said it is not the case that SMRs would necessarily be easier or faster to assess because of their size. Some designs use novel technologies which would require regulators to build their knowledge of the design. Public confidence in SMRs would suffer if it were perceived that standards were being lowered to facilitate speedier design assessment.

There is already a provisionally agreed schedule which provides for one SMR design – following a selection process and subject to Government policy decisions – to potentially begin a Generic Design Assessment (GDA) in 2017. The Government is expecting one of the eight sites on the Nuclear National Policy Statement to be proposed. At some stage though, it says, an exercise to identify new sites, both for new full-scale nuclear power stations and potentially for SMRs, is likely to be necessary, and is considering what form this might take.

The Government says it recognises the importance of engaging with the public on SMRs, because there is a potential for these reactors to be distributed in greater numbers across the country in closer proximity to larger centres of population than existing nuclear sites.

11. Radioactive waste implications

The Committee on Radioactive Waste Management (CoRWM) has looked at the waste implications of a 75GW programme which would be equivalent to a programme of over 50 new large-scale reactors. It said that since the Government has, so far, been mainly talking about the waste inventory from only a 16GW nuclear new build programme, it should consider defining a maximum size for a deep geological facility (GDF) and make clear that we might need multiple GDFs. (37) The Environment Agency (EA) has already set a limit on the risk that may be caused by the burial of radioactive wastes of 10^{-6} (i.e. one in a million). (38) Figures from the NDA Disposability Assessment Report for waste arising from new EPR reactors (39) suggest that a programme equivalent to 50 large reactors would require around four GDFs.[1] Despite the obvious waste management problems caused by such a programme, the Government continues to fund research into new reactor types and promote its long-term nuclear strategy.

12. Conclusions

Disquiet over the high cost and delays at Hinkley Point C – some of it from within the nuclear community – and signs of a faltering global nuclear renaissance – have led to questioning whether the long-established conventional wisdom that bigger units are cheaper than small reactors is any longer true. The US Department of Energy (DOE) has built up a momentum for SMRs by throwing hundreds of millions of dollars in cost-shared funding to jump-start the industry.

For some in the industry SMRs are seen as a way to reduce costs and speed up construction by using large-scale standardized manufacturing that will churn out dozens, if not hundreds, of identical plants, each of which would ultimately produce cheaper kilowatt-hours than large one-off designs. But first someone needs to build a massive supply chain. Money for that would presumably come from customer orders - if there were any. The problem is it appears that no one actually wants to buy one. (40)

So what are the prospects for small reactors, both in the UK, Ireland and globally? Former CoRWM Chair, Professor Gordon Mackerron, says no SMR (properly defined) has yet been commercialised anywhere in the world, and work on them has been waning because the developers cannot find a market. This is unsurprising as their cost per unit of output is higher than the already expensive conventional, larger reactors, unless hundreds can be sold to give manufacturing economies. Mackerron says we should not expect a significant contribution from SMRs by 2050. (41)

None of the designs, including the most credible, which are based on scaled-down versions of currently deployed PWR technology, is yet ready. NNL speaks of 'detailed technical challenges' not yet resolved. It is therefore no surprise that no company has yet built a single SMR let alone made a commitment to building the large numbers that would be needed to make the economic case remotely credible. And the safety licensing process that will need to follow design completion would, according to the Chief UK Nuclear Inspector, take up to 6 years in the UK.

The cost of SMRs is essentially unknowable at the moment, but there is evidence to suggest they will be even more expensive than existing reactors. Despite this NNL suggests two scenarios, 'niche' and 'parity' (of cost). It concludes that the world market could be only just over 5 GW in 2035 in its 'niche' scenario but 65-85GW in 'parity'. It then suggests a potential UK market of between 7GW and 21GW in 2035. Mackerron says this latter number is frankly not credible under

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[1] The NDA Disposability Assessment suggests *"…a risk of 5.3 x 10^{-7} per year for the lifetime arisings of a fleet of six EPR reactors"* This is more than half the total risk of 10^{-6} allowable for a GDF. Clearly a GDF with spent fuel from 12 new EPR reactors would exceed the risk targets set by the EA for a single GDF. So 50 reactors would require at least 4 dumps.

any conceivable circumstances. These hoped-for UK markets are also linked to the idea that the UK could become a major technological player in SMR technology, a view that seems tinged almost with fantasy, given that all significant SMR development to date has been outside the UK:. In the USA for example the Obama administration has pledged a further $217 million to NuScale, following substantial earlier Federal funding for two SMR designs. (42)

The fact that the UK Government is already considering what sort of process might be needed to propose new sites for nuclear reactors shows that it is serious about its long-term nuclear strategy. What is most worrying to the NFLA about these future nuclear scenarios is that the UK Government (and perhaps the Irish Government as well) is failing to develop alternative non-nuclear scenarios to replace them when they turn out to have been a delusion, which they surely will. In the NFLA's view, the political will of both the UK and Irish Governments should be focused on such non-nuclear scenarios.

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