Prospects of Small Modular Reactors in the Czech Republic

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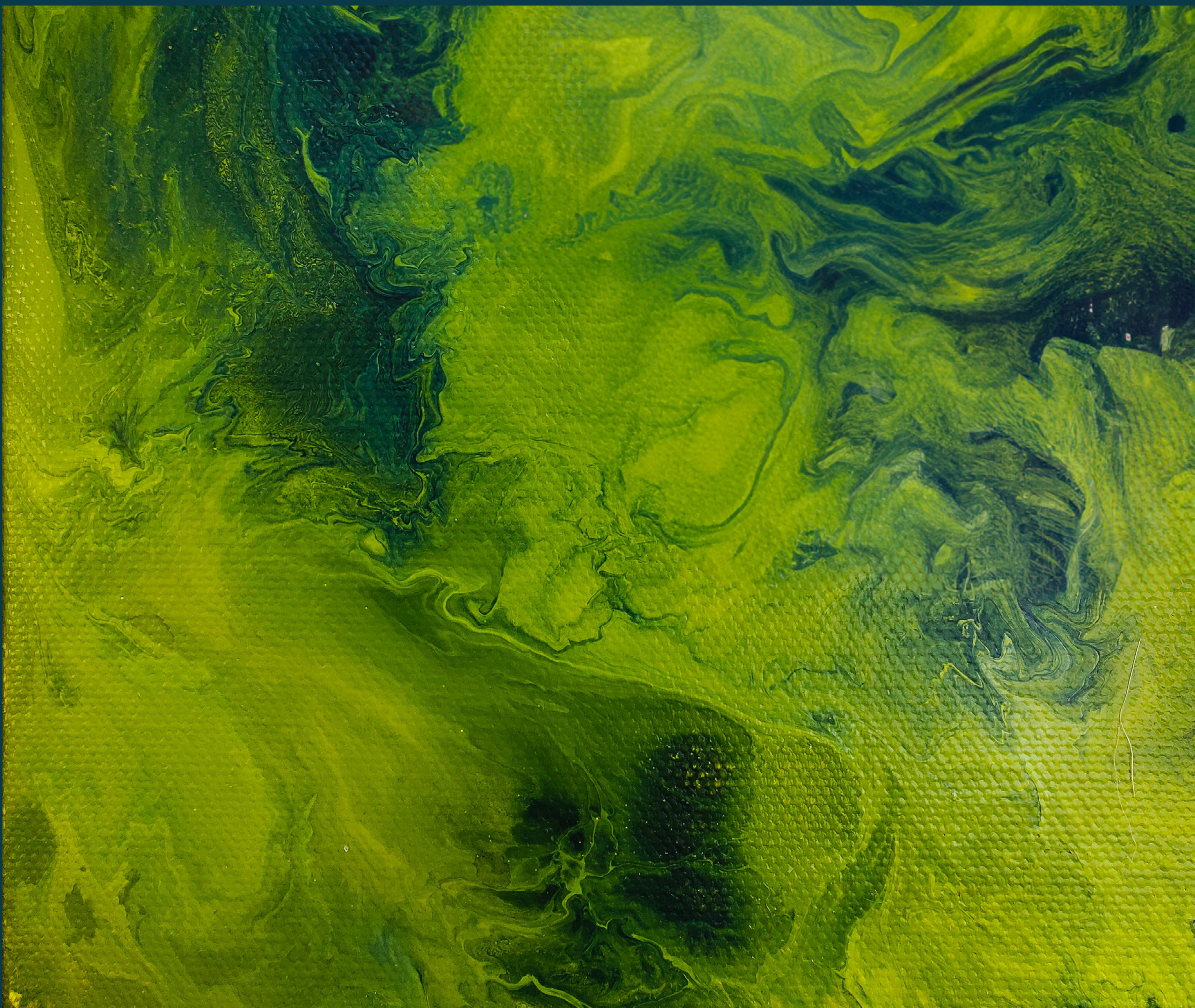

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Dear Readers,

Nuclear energy in the Czech Republic has enjoyed seemingly unshakable long-term political and public support despite the security, economic and environmental arguments which play a significant role in the debate about nuclear power in a number of other countries. The Russian invasion of Ukraine even strengthened this tendency – nuclear power is supposed to help reduce our dependence on fossil fuels and become one of the key pillars of the Czech energy mix. At the same time, the construction of new blocks of nuclear power plants is not only unimaginable without billions from the state budget, but is also experiencing constant delays. For this, the electricity produced by nuclear power plants is significantly more expensive compared to electricity produced by renewable sources, which are proving increasingly economically advantageous.

According to the World Nuclear Industry Status Report 2022, the price of nuclear energy has increased by more than a third in recent years, while, for example, large photovoltaic systems have become cheaper by 90 % over the same period.

The response of some nuclear power advocates to these problematic aspects is the Small Nuclear Reactor, which is supposed to be safer, more flexible, cheaper and faster to build. In the Czech Republic the energy company ČEZ is pushing for their launch. Public debate on this topic is not taking place so far and there are very few information sources available. It is therefore time to take a look at the parameters of the reactors which are coming into consideration for the Czech market and also at how their development has actually progressed.

What are the arguments in their favor and how realistic are they? What is the chance we will see their mass construction in the Czech Republic?

This publication contributes the views of experts and offers the most important findings in the topic. Its author is Professor Stephen Thomas from the University of Greenwich who has more than 25 years of experience conducting research in the field of energy policies. Thomas also cooperates with renowned journals, is a member of the editorial board of the Utilities Policy and the Coordinating Editor of Energy Policy. The current situation in the Czech Republic is described in a chapter by Edvard Sequens, the energy consultant for the Calla organization.

We hope this analysis contributes the necessary information and incentivizes debate about the reasonableness of of building Small Modular Reactors compared to alternatives such as renewable energy.

We wish you a stimulating read!

Adela Jureckova, Head of Office, Heinrich Böll Stiftung Prague
Klara Pleskacova, Ecology Program Coordinator, Heinrich Böll Stiftung Prague

Small Modular Reactors for the Czech market

Stephen Thomas

1. Introduction

Small Modular Reactors (SMRs) are being widely promoted as offering a cost-effective way to reduce greenhouse gas emissions in the electricity generation sector as well as to revive the fortunes of the nuclear industry. However, they encompass a wide range of sizes and technologies that mean it is not sensible to talk about them as a set of technologies. Conventionally, SMRs are defined as reactors of 20-300MW electrical output suitable for supplying power to a grid,[1] but several designs being developed which vendors describe as SMRs are significantly larger than 300MW. For example, the Rolls-Royce SMR is currently expected to produce 470MW. This would make it about the same size as each of the four reactors in operation at Dukovany and larger than Fukushima Daiichi 1 (439MW), one of the reactors that melted down in Japan in 2011. In this report, we examine reactors designed to produce between 20MW and 500MW. Reactors smaller than 20MW, sometimes known as micro-reactors,[2] are being developed to supply heat and power to industrial facilities or isolated communities or to produce hydrogen. These designs are not considered here.

In terms of technologies, some of the SMR designs are basically smaller versions of the dominant power reactor types. These are the two types of Light Water Reactor (LWR), the Pressurised Water Reactor (PWR), the technology installed at Temelín and Dukovany, and the similar Boiling Water Reactor (BWR).[3] They use ordinary water [4] as a coolant (the medium that transfers the heat from the reactor to the power generation plant) and as a moderator (the material that controls the nuclear reaction).[5] Water is not the best coolant or moderator, but it is cheap. The experience going back more than 60 years of operating LWRs does give some confidence, if not full assurance, that LWR SMRs can be a reasonably reliable source of power. Several of the PWR designs differ from the large reactors by being 'integrated' designs, with the reactor core, primary cooling loop, steam generators and any required emergency cooling all contained within a single reactor vessel. This is said to give improved safety by reducing accidents due to coolant loss. However, it does require a larger reactor vessel, and for

1. LIOU, Joanne. What Are Small Modular Reactors (SMRs)? Online. In: International Atomic Energy Agency. 4. 11. 2021. *https://tinyurl.com/236j72sc*

2. Microreactors. Online. In: Idaho National Laboratory. *https://tinyurl.com/zaru254v*

3. Of 437 operating reactors, as of the close of 2021, 303 were PWRs and 67 were BWRs.

4. Some types of reactors use 'heavy' water as coolant and a moderator. It contains deuterium, a heavier and rarer isotope instead of hydrogen atoms. Of the completed reactors, a total of 47 PWRs use 'heavy' water.

5. Water is not the best coolant or moderator, but it is much cheaper than an alternative coolant like helium or moderators such as graphite. Given its lower efficiency, the proportion of the 'fissile' isotope in enriched uranium is increased from its natural 0.7% to roughly 4-5 %. Another limitation to using water is the operating temperature of both BWRs and PWRs is lower than 400 degrees Celsius, which is too low or some industrial processes such as the synthesis of hydrogen through efficient catalysis.

the larger SMRs, such as the Rolls-Royce version, an integral design is not used. Some designs also emphasise the use of so-called passive safety, under which, in an accident situation, the reactor would not rely on engineered safety systems coming into operation to bring the reactor back to a safe condition. For example, it would rely on natural convection to cool the reactor, rather than an emergency core cooling system. The Westinghouse AP1000 is the only large reactor design in operation that relies heavily on passive safety. Other designs claim some use of passive safety, but their main safety systems are the traditional, active ones.

SMRs using designs other than PWR and BWR are sometimes termed 'advanced' reactors. However, this is misleading, as they are not new concepts and all date back half a century or more. In the cases of the Sodium-cooled Fast Reactor (SFR) and the High Temperature Gas-cooled Reactor (HTGR), they have been built as prototype and demonstration plants, generally with poor results. For example, the Super Phenix (France) SFR (1200MW) generated minimal amounts of power in the five years it was in service before it was abandoned in 1988. The 300MW THTR-300 (Germany) HTGR generated only small amounts of power for two years before it was abandoned in 1988. Other designs, like molten salt reactors and lead-cooled fast reactors, have been talked about for decades but never built as a power reactor, not even just at prototype scale. All 'advanced' reactors will require expensive and, in some cases, yet to be developed materials to handle the conditions (e.g., high temperatures, pressures and corrosive materials) they would be required to deal with. Micro-reactors also generally use one of the reactor types categorised as 'advanced'. Unlike LWRs, it cannot be assumed that advanced reactors will probably be reliable power generators, much less that they will be a competitive option. In the timeframe examined by the Czech Republic, advanced reactors are highly unlikely to be commercially available and micro-reactors will not meet its needs. Therefore, we are focusing on the LWR SMRs which might be available in the timeframe the Czech Republic is considering, in the size range of 20-500MW. In practice, the smallest LWR SMR being considered is the 77MW NuScale PWR, while the largest is the 470MW Rolls-Royce SMR.

2. What are the claims for SMRs?

SMR proponents claim SMRs will be cheaper per unit of electrical output and quicker to build than conventional large reactors, as well as less prone to cost escalation and construction delays. It bases these claims on the following:

1. **The components would be built on production lines rather than through one-off fabrication, as is typically the case for major components in large reactors.**
2. **The components would be delivered in modules which would just require assembly on-site, rather than the extensive engineering on-site required by most large reactors.**
3. **Their smaller size would allow them to be built more quickly and with less risk of delays.**
4. **Their smaller size and lower total cost would make it easier for them to be financed.**
5. **In some cases, the designs can be built incrementally, adding additional reactors at the site using central services as demand dictates.**

We evaluate these claims in section 5.

3. What is required to bring a reactor design to market?

Reactor vendors always give the impression that their designs are much closer to being commercially available than they are. No SMR design is commercially available to order yet. Experience suggests that to bring a reactor design from inception to being commercially available will cost more than US$1bn and take more than a decade. This is an amount that is beyond the capability of most prospective SMR vendors, and bringing most designs to commercial availability will require large government subsidies and guarantees. Many designs are just at the design concept stage. After this, the basic design must be carried through, followed by the detailed design work needed to provide the details needed for it to be ordered. It is the detailed design work that is the most expensive element. Given the poor record of many reactor designs, prospective customers are likely to want to see a demonstration of the technology at commercial scale, which is again likely to require public subsidies and underwriting. Several practical steps are needed to achieve the goal of a commercially available design.

3.1 Regulatory approval

A first requirement is that the design should have undergone an in-depth assessment by an experienced, credible safety regulatory body. Canada has been the most aggressive country in trying to deploy SMRs. The government has said it wants Canada 'to lead the world in this game changing technology' despite none of the designs being pursued having Canadian origins.[6] To support this, the Canadian Nuclear Safety Commission (CNSC) has carried out initial assessments which will determine whether, in principle, the design will be able to satisfy the in-depth assessment needed before a construction permit can be issued for a specific project.

The CNSC offers a three-phase 'pre-licensing vendor design review'.[7] The first phase carries out 'an overall assessment of the vendor's nuclear power plant design against the most recent CNSC design requirements for new nuclear power plants in Canada' as well as 'all other related CNSC regulatory documents and Canadian codes & standards'. Given that the most recent order for a power reactor in Canada (the Darlington station) was placed more than 40 years ago, it is not clear how well developed CNSC's 'most recent design requirements' are. The second phase tries to identify 'any potential fundamental barriers to licensing the vendor's nuclear power plant design in Canada'. The third phase 'allows the vendor to followup on certain aspects of Phase 2 findings by seeking more information from the CNSC about a Phase 2 topic; and/or asking the CNSC to review activities taken by the vendor towards the reactor's design readiness, fol-

6. About the Action Plan. Online. In: Canada's Small Modular Reactor. SMR Action Plan. *https://smractionplan.ca/*

7. Pre-Licensing Vendor Design Review. Online. In: Canadian Nuclear Safety Commission. *https://tinyurl.com/22rmw5nn*

lowing the completion of Phase 2.' The CNSC clarifies that the pre-licensing vendor design review process 'does not certify a reactor design and does not involve the issuance of a license under the Nuclear Safety and Control Act. It is not required as part of the licensing process for a new nuclear reactor facility. The conclusions of a design review do not bind or otherwise influence decisions.'

Table 1 shows the status of reviews carried by CNSC. The only LWRs being evaluated are the GE-Hitachi BWRX-300 and the Holtec SMR-160. NuScale said that it submitted a combined phase 1 and 2 pre-licensing review application for its 60MW PWR design to CNSC in 2020, but this design does not appear in the CNSC's 2023 list of reactors being evaluated and, given that the 60MW design has been abandoned, it is not clear whether NuScale is still pursuing a design review in Canada.[8] Holtec reported its SMR-160 PWR design had completed phase 1 of the CNSC review in 2020 [9] and that it planned to pursue phase 2 in 'the near future'.

Regulatory bodies in other countries carry out similar reviews to determine whether, in principle, a design can be developed that will meet the required standard, but Canada is alone in carrying out such a large number of reviews. As is the case in Canada, these design reviews do not certify the design as licensed, just that a detailed design could be made licensable.

It is only when a comprehensive design review has taken place that the full design specification of the plant, and therefore a credible estimate of its cost, can be determined. The US Nuclear Regulatory Commission (NRC) carries out such reviews under its Design Certification programme established more than 30 years ago [10] and in the UK, the Office of Nuclear Regulation (ONR) carries out a similar process under its Generic Design Assessment (GDA) programme set up in 2009.[11] The UK GDA process was opened to SMRs in May 2021, although only one design, the Rolls-Royce SMR PWR, has entered the process.[12] Reactor designs that pass this type of assessment are approved for construction at any site for a set period (the USA specifies 15 years, the UK 10 years) subject only to local siting requirements. The US and UK governments generally require vendors to pay the cost of design assessments.

8. NuScale Submits Phase 1 and 2 Combined Pre-Licensing Vendor Design Review to Canadian Nuclear Safety Commission. Online. In: NuScale. 7. 1. 2022. *https://tinyurl.com/wcfwdxpm*

9. Holtec Successfully Completes Canadian Nuclear Safety Commission Phase 1 Vendor Design Review. Online. In: Holtec International. 20. 8. 2020. *https://tinyurl.com/nhhx7dm3*

10. Design Certification Applications for New Reactors. Online. In: United States Regulatory Commission. *https://tinyurl.com/3rwnxmyk*

11. Generic Design Assessment (GDA) of new nuclear power stations. Online. In: Office for Nuclear Regulation. *https://www.onr.org.uk/new-reactors/*

12. Policy Paper. Advanced Nuclear Technologies. Updated 15 August 2023. Online. In: GOV.UK. Aktualizováno 15. 8. 2023. *https://tinyurl.com/4nhcxd9w*

Table 1: Pre–licensing vendor design reviews in Canada

DESIGN	TYPE	OUTPUT (MWE)	VENDOR	REVIEW START	STATUS
IMSR-400	Molten salt	200	Terrestrial Energy	Phase 1 4/16 Phase 2 12/18	Complete Complete
ARC-100	Sodium fast reactor	100	ARC Nuclear Canada	Phase 1 9/17 Phase 2 2/22	Complete In progress
Moltex Energy Stable Salt	Molten salt	300	Moltex Energy	Phase 1 12/17 Phase 2	In progress
SMR-160	PWR	160	Holtec	Phase 1 7/18 Phase 2	Complete
BWRX-300	BWR	300	GE-Hitachi	Phase 2 1/20	Complete
Xe-100	HTGR	80	X Energy	Phase 2 7/20	In progress

Source: https://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm
Notes:
1. In case of the BWRX-300 anf the Xe-100 it is a combination of the first and second stages of assessment.
2. Three reactors with an output below 20 MWe are not listed.
3. The SFR is a sodium cooled fast reactor and the IMSR (Integral Molten Salt Reactor) is an integrated molten salt cooled reactor.

3.2 A reference plant

Given the poor record, particularly in the past couple of decades, of new designs being built on time and at cost, buyers and their financiers are reluctant to buy a first-of-a-kind plant and want to see an operating plant in action that demonstrates its costs and performance as well as its ability to satisfy safety regulatory requirements. This demonstration plant is often sited in the home country of the vendor and is likely to require public subsidies and other forms of government support.

3.3 A credible supply chain

Many SMR designs are being offered not by traditional vendors, but by companies with no experience of supplying power generating plants of any type. These are sometimes start-up companies or companies with no experience of building a power plant of any type. To be credible, such companies will need to have partner companies with a strong track record in power plant (preferably nuclear) construction. For example, the NuScale corporation has the Fluor Corporation as its majority owner. The vendors will need to establish a supply chain with component manufacturers that meet the standards required for nuclear components (for example ASME (American Society of Mechanical Engineers) accreditation).[13] In the past two decades, only a handful of reactors have been ordered from vendors other than those from Russia and China, so the supply chain for reactors of any type will need to be rebuilt if large numbers of orders are to be placed.

3.4 Demonstration of costs

Given that economic claims depend on cost reductions from producing components on production lines, the costs can only be determined with some degree of accuracy when several reactors built using production lines have been completed. This does produce a 'Catch 22' problem. Production lines are expensive to set up and, once complete, need a flow of orders. This is only likely to be possible when a reference plant is in operation to convince potential buyers that the design is not a major economic risk. So, unless a customer is willing to take the risk of placing a significant number of orders before the first plant of the design is completed, the production lines will have to be immediately mothballed as soon as the components for the first plant have been made. Alternatively, components could be fabricated on a one-off basis for the initial reactors, as is the case for large reactors. One-off fabrication methods would not demonstrate the actual costs of series production.

13. Nuclear Component Certification.Online. In: The American Society of Mechanical Engineers. *https://tinyurl.com/3byy5wzu*

4. UK experience

In the UK government's November 2015 Budget, the government announced it would spend at least £250m by 2020 on 'innovative nuclear technologies'. This appears to have been almost exclusively for SMRs, including a competition to identify 'the best SMR for the UK'.[14] No details of nuclear technologies other than SMRs were mentioned, so it must be assumed the vast majority of funds were expected to be offered for SMRs.

In March 2016, the government launched the competition with a call for expressions of interest in supplying SMRs. The first phase of this competition was expected to be complete by late 2016, when an 'SMR Delivery Roadmap' was to have been published.[15] The competition was never completed, the Roadmap was never published (if it was actually produced), and there is no evidence any of the budget was spent.

Nevertheless, in July 2023, the UK government announced another competition to identify the best SMR design for the UK. However, the plan did not anticipate that a Final Investment Decision on the successful design(s) would be taken until 2029.[16] The Rolls-Royce design was not mentioned and so, unless it is on a different development track yet to be identified, Rolls-Royce's claims that a Rolls-Royce SMR could be in operation in 2029 are clearly in tatters.[17] It remains to be seen whether this new competition will be more successful than its predecessor

14. CARRINGTON, Damian. George Osborne puts UK at the heart of global race for mini-nuclear reactors. Online. In: The Guardian. 24. 11. 2015. *https://tinyurl.com/yxep7b5n*

15. UK government launches SMR competition. Online. In: World Nuclear News. 18. 3. 2016. *https://tinyurl.com/2p8pc9rj*
Small Reactors Competition: phase one. Online. In: GOV.UK. 17. 3. 2016. *https://tinyurl.com/2s4cbh7u*

16. Small Modular Reactors: competitive technology selection process. Online. In: GOV.UK. 18. 7. 2023. *https://tinyurl.com/3swz48c9*

17. Rolls-Royce hopes for UK SMR online by 2029. Online. In: World Nuclear News. 19. 4. 2022. *https://tinyurl.com/yvnbk94k*

5. The possible designs

Seven designs have been mentioned as relevant to the Czech Republic (see Table 2).

5.1 GE-Hitachi BWRX-300

The 300MW BWRX-300 was announced in 2018 and is a scaled-down version of the 1500MW GE-Hitachi ESBWR.[18] The ESBWR (Economic Simplified Boiling Water Reactor) design was given generic approval by the US NRC in 2014 after a nine-year process. It did start the UK GDA process in 2008, but was withdrawn a year later because there was no prospect of UK orders.[19] It has not been offered to any potential customers worldwide, not least due to its high expected cost, and no orders are in prospect. US utilities Dominion and Exelon are providing financial support for the design work for the BWRX-300, and it has support from the US Department of Energy, but given the apparently early stage of its development, it may be some way from being ready for commercial deployment. A pre-application review of the design was started by the US NRC in December 2019 but was still incomplete as of July 2023.[20]

In March 2023, GE-Hitachi claimed BWRX-300 had become the first SMR design to complete the first two phases of the Canadian pre-licensing design review. Nevertheless, the CNSC found '...the review did reveal some technical areas that need further development in order for GEH [GE-Hitachi] to better demonstrate adherence to CNSC requirements.'[21] GE-Hitachi published a press release in January 2023 that seems to imply that Ontario Power Generation (OPG) had placed a firm order for a BWRX-300 ('GE Hitachi signs contract for the first North American small modular reactor') with a target of first power by 2029.[22] Subsequently, OPG announced it expected to order three further BWRX-300s to be complete between 2034 and 2036.[23] All four units would be at the Darlington site, where four large reactors are already in operation. Closer reading of these announcements shows these are not firm orders and will not be until the design receives full approval from the CNSC.[24] In October 2022, OPG submitted an application to CNSC to build the first BWRX-300 at Darlington, and it expects to make an investment decision by the end of 2024.

18. New Plants. Online. In: Hitachi. *https://tinyurl.com/bdk6kr27*

19. EPR reactor design meets UK approval. Online. In: World Nucelar News. 13. 12. 2012. *https://tinyurl.com/bdhuxt4j*

20. GEH BWRX-300. Online. In: United States Nuclear Regulatory Commission. Aktualizováno 6. 10. 2022. *https://tinyurl.com/52dbrrnv*

21. BWRX-300 completes Phases 1 & 2 of Canadian pre-licensing review. Online. In: World Nucelar News. 15. 3. 2023. *https://tinyurl.com/493tjdfc*

22. GE Hitachi Signs Contract for the First North American Small Modular Reactor. Online. In: General Electric. 27. 1. 2023. *https://tinyurl.com/29hzdmcb*

23. Additional SMRs in the pipeline for Darlington. Online. In: World Nuclear News. 7. 7. 2023. *https://tinyurl.com/bf6bruv7*

24. Nuclear facility – Darlington New Nuclear Project. Online. In: Canadian Nuclear Safety Commission. Aktualizováno 19. 9. 2023. *https://tinyurl.com/3a95745v*

There is interest in the design in Poland,[25] although a firm order is clearly a long way off. In Estonia, Fermi Energy, a small private company set up in 2006 with the objective of developing nuclear energy in Estonia, has selected BWRX-300 for potential deployment there.[26] In February 2023, the Canadian and Polish safety regulatory bodies announced an agreement to cooperate on the assessment of the design.[27] In May 2023, the Polish safety authorities, Państwowa Agencja Atomistyki (PAA), announced the design met their safety requirements.[28] However, given that this was no more than approval in principle, and given the PAA's lack of experience in reviewing reactor designs, this has limited significance.

In the UK, in December 2022, GE-Hitachi asked the British government to request the safety regulator to carry out a safety review under the Generic Design Assessment (GDA) programme.[29] By July 2023, the British government had not published a decision on this request. In May 2023, the ONR confirmed it had not started any review of the BWRX-300.[30]

The Tennessee Valley Authority, a US federally-owned utility, has received an early site permit to build SMRs at its Clinch River site of up to 800MW capacity, with the BWRX-300 seen as having a strong position.[31]

In 2020, GE-Hitachi signed a memorandum of understanding with ČEZ to examine the feasibility of deploying the BWRX-300 in the Czech Republic.[32]

25. Poland's Orlen Synthos Green Energy seeks formal approval for SMR sites. Online. In: Nuclear Engineering International. 2. 5. 2023. *https://tinyurl.com/nhhetj2t*

26. Fermi Energia chooses GE Hitachi's BWRX-300 as the technology for planned SMR nuclear power plant in Estonia. Online. In: Fermi Energia. 8. 2. 2023. *https://tinyurl.com/9jjhtf8n*

27. Canadian and Polish regulators announce SMR collaboration. Online. In: World Nuclear News. 14. 2. 2023. *https://tinyurl.com/yf97snbp*

28. BWRX-300 meets Polish safety requirements, says regulator. Online. In: World Nuclear News. 24. 5. 2023. *https://tinyurl.com/bdetbdtn*

29. GE Hitachi Submits Generic Design Assessment Application in the UK for the BWRX-300 Small Modular Reactor. Online. In: General Electric. 20. 12. 2022. *https://tinyurl.com/musfnvtt*
Policy Paper. Advanced Nuclear Technologies. Online. In: GOV.UK. 15. 8. 2023. *https://tinyurl.com/4nhcxd9w*

30. BEIS-funded Mature Technology evaluation of GE Hitachi's BWRX-300 Small Modular Reactor. Online. In: Office for Nuclear Regulation. 17. 11. 2020. *https://tinyurl.com/5xkwpze3*

31. TVA, GEH cooperate on BWRX-300 deployment at Clinch River. Online. In: World Nuclear News. 3. 8. 2022. *https://tinyurl.com/4jc5f6dn*

32. GE Hitachi Nuclear Energy and ČEZ Announce Small Modular Reactor Technology Collaboration in the Czech Republic. Online. In: ČEZ Group. *https://tinyurl.com/32247bd2*

5.2 NuScale SMR

The NuScale PWR SMR [33] has a long development history dating back to the early 2000s, based on research carried out for the US Department of Energy by Oregon State University. The NuScale company was set up in 2007.[34] The original design was to produce 35MW and was progressively upgraded to 40MW, 50MW, 60MW and, in 2020, to 77MW.[35] NuScale suggested that it would be built in clusters of 12 reactors but, with the upgrade to 77MW, decided to also offer the design in clusters of four and six reactors in addition to the original 12. In 2008, NuScale requested a pre-application review by the US Nuclear Regulatory Commission (NRC), and in 2011 the Fluor Corporation (a large US-based engineering and construction firm) became the primary investor in NuScale. NuScale claims the reactor is suitable for a variety of uses including desalination and process heat as well as power generation, and makes strong claims for its load-following capabilities.

In 2013, NuScale received US$217m from the US Department of Energy to develop the design and secure NRC generic approval. In the same year, Rolls-Royce joined the NuScale development programme. In 2016, the design was submitted to the NRC for review as a cluster of 12 reactors - the only SMR that had been submitted to the NRC by May 2023 [36] - and, in 2020, the 50MW design received approval. As a result of the 50% increase in power rating that the 77MW version represented over the 50MW version that had been reviewed, NuScale applied to the NRC in January 2023 for a review of the 77MW design, built as a cluster of six reactors.[37] In responding to NuScale's application for a review of the 77MW design, the NRC identified significant issues that would need to be resolved before the review could commence.[38] The NRC began its review in March 2023.[39]

The NuScale design was reported to be under preliminary review by the Canadian Nuclear Safety Commission (CNSC).[40] However, in May 2023, NuScale did not appear in CNSC's list of reactor designs undergoing pre-licensing review.

By the end of 2021, Fluor claimed it had spent US$600m of its own funds developing the design.[41] Despite its long development history, it is far from being ready for commercialisation. The lead project, announced in 2015, is for a cluster of reactors in Utah to be owned by Utah Associated Municipal Power Systems (UAMPS).[42] This was originally expected to be for 12 reactors (600MW) when the design was for 50MW, but the decision to upgrade the design to 77MW and the difficulty of finding investors led to the project being downscaled to a cluster of six reactors (462MW) with expected completion in 2030, four years later than originally planned.

There are about 50 members of UAMPS expected to take small stakes, typically 2-4MW, in the plant.[43] In January 2023, UAMPS announced the forecast cost of the six reactors had increased from US$5.3bn in 2021 to US$9.3bn (including US$2.5bn in interest during construction). This made the overnight cost (excluding interest during construction) nearly US$15,000/kW. The US Department of Energy is offering a subsidy to the construction cost of US$1.2bn.[44] The expected cost of the power increased from US$58/MWh to US$89/MWh. The US Department of Energy is offering additional subsidies worth US$30/MWh, so the total expected cost is about US$120/MWh.[45] Despite these subsidies, it has proved difficult to

33, 34. Company History. Online. In: NuScale. *https://www.nuscalepower.com/en/about/history*

35. NuScale Power Releases Updated Evaluation for 77 MWe Module Clean Hydrogen Production. Online. In: Nuscale. 12. 9. 2020. *https://tinyurl.com/35xz68n6*

36. Design Certification Applications for New Reactors. Online. In: United States Regulatory Commission. *https://tinyurl.com/27k2t5bn*

37. NuScale US460 Standard Design Approval Application Review. Online. In: United States Nuclear Regulatory Commission. Updated 1.8.2023. *https://tinyurl.com/2p9nra5w*

38. TESFAYE, Getachew. ACCEPTANCE REVIEW OF THE NUSCALE US460 STANDARD DESIGN APPROVAL APPLICATION. In: United States Nuclear Regulatory Commission. 17. 3. 2023. *https://tinyurl.com/3jksmjsu*
SMITH, Grant, LACEY, Anthony. Small size, big problems: NuScale's troublesome small modular nuclear reactor plan. Online. In: EWG. 11. 7. 2023. *https://tinyurl.com/m3kjyk9e*

39. NRC to Begin Reviewing Portions of NuScale's Small Modular Reactor Standard Design Approval Application. Online. In: United States Nuclear Regulatory Commission. *https://tinyurl.com/yets6cw6*

40. Pre-Licensing Vendor Design Review. Online. In: Canadian Nuclear Safety Commission. Updated 20.4.2023. *https://tinyurl.com/mw3fr9bx*

41. MERSHON, Brian, LANDKAMER, Jason. Fluor-Backed NuScale Power Signs Agreement to Accelerate Small Modular Reactor Commercialization. Online. In: Fluor. *https://tinyurl.com/ycx4ywv4*

42. Growing the SMR Market. Online. In: NuScale. *https://www.nuscalepower.com/en/projects*

43. UAMPS Members. Online. In: UAMPS. *https://www.uamps.com/Members*

44, 45. SCHLISSEL, David. Eye-popping new cost estimates released for NuScale small modular reactor. Online. In: Institute for Energy Economics and Financial Analysis. 11. 1. 2023. *https://tinyurl.com/yudax6kk* get firm commitments [46] from the UAMPS members to buy the power and by January 2023, only 120MW of the 462MW had been firmly committed The project is therefore hanging in the balance.

It is clear that the components for the UAMPS project will not be built on production lines, and agreements have been completed between NuScale and various component suppliers to supply components for the reactor.[47] The components would be manufactured at multiple locations and shipped to a single location for assembly prior to installation at the site.[48] So even if UAMPS is built, the economics, specifically the benefit of production line manufacture, will not be demonstrated.

The federally-owned Tennessee Valley Authority has received an early site permit to build SMRs at its Clinch River site for up to 800MW capacity.[49] However, while the NuScale design was originally seen as a frontrunner,[50] the BWRX-300 may now be the favourite.[51]

In 2016, NuScale confirmed its intention to enter the UK's competition to select the best SMR design for the UK. In 2016, Sheffield Forgemasters, a UK company, joined the NuScale development team, which already included Rolls-Royce. However, since then there has been little sign of progress in the UK with the NuScale design and Rolls-Royce is now concentrating on its own design.

Other markets which have expressedan interest in the NuScale SMR include:

- **Jordan, through an agreement in 2019 with the Jordan Atomic Energy Commission, apparently superseding an earlier agreement between Jordan and Rolls-Royce.**[52]
- **Romania, through an agreement with Romania's nuclear generating company, Nuclearelectrica.**[53]
- **Canada, through an agreement in 2018 with the Canadian nuclear power operators, Ontario Power Generation and Bruce Power.**[54]

The only market that seems to be making progress is Romania, and at the G7 summit in May 2023, a package of funding worth US$275m was announced to build six NuScale SMRs. However, all that was signed were letters of intent, no site had been identified, and the announcement was far from representing a firm order.[55]

NuScale is claiming the settled down construction costs would be $4200/

46. Nucleonics Week „UAMPS says members boost capacity commitments, agree to advance Idaho SMR plant", 1.2.2023, s. 1.

47. NuScale Power Signs Agreement with Doosan Enerbility and Export-Import Bank of Korea, Highlighting Global Supply Chain Development Opportunities. Online. In: NuScale. 25. 4. 2023. *https://tinyurl.com/46hxeh93*

48. REYES, Jose. NuScale Nonproprietary Copyright © 2021 NuScale Power, LLC. NuScale Response to NASEM Questionnaire. Online. In: NuScale. 14. 7. 2021. *https://tinyurl.com/5ynfrnnc*

49. Issued Early Site Permit - Clinch River Nuclear Site. Online. In: United States Nuclear Regulatory Commission. Updated 21. 9. 2022. *https://tinyurl.com/4w4vzyaw*

50. Inside NRC „NRC board recommends TVA be given early permit for work on SMR project". 21. 1. 2019.

51. TVA, GEH cooperate on BWRX-300 deployment at Clinch River. Online. In: World Nuclear News. 3. 8. 2022. *https://tinyurl.com/4jc5f6dn*

52. NuScale SMR to be considered for use in Jordan. Online. In: World Nuclear News. 15. 1. 2019. *https://tinyurl.com/nhh4f6xk*

53. Romania to explore NuScale SMR deployment. Online. In: World Nuclear News. 19. 3. 2019. *https://tinyurl.com/4z4tzhpc*

54. Nuclear News „OPG to support NuScale Power's SMR efforts", December 2018.

55. Romania's NuScale SMR plan gets USD275 million boost. Online. In: World Nuclear News. 22. 5. 2023. *https://tinyurl.com/38a5yjv8*

kW,[56] which is about half the level of large reactor projects in the USA, the UK, France and Finland and about a third of the latest forecast for UAMPS. However, the NuScale design is still far from finalised, so current estimates must be seen as promotional. It is much smaller than its main competitors, so the lost scale economies compared to large reactors will be correspondingly harder to balance by production line manufacture. If the UAMPS project does not go forward by providing a reference plant customers can use to evaluate the design, this will be a serious blow to its commercial prospects. In 2019, NuScale signed an agreement with ČEZ to explore deployment in the Czech Republic.[57]

5.3 Holtec SMR-160

The SMR-160 is a 160MW integral PWR under development in the USA since 2010.[58] It is claimed to have similar characteristics to most other LWR SMRs, such as modularity, passive safety, and factory production of major components. The developers talk about clusters of up to 10 reactors. Holtec is collaborating with Mitsubishi Electric (Japan), SNC Lavalin (Canada) and Exelon, a US utility, in the development of the design. In 2019, Holtec signed an MOU with Ukraine which was planned to lead to production and deployment of the SMR-160 in Ukraine. Its design is under review by the CNSC, which was collaborating with the Ukraine State Nuclear Inspectorate in its review.[59]

Holtec has been working with ČEZ since 2019 on the commercial and technical evaluation of the Holtec design.[60] In October 2022, Holtec announced a memorandum of agreement with Škoda Praha, part of the ČEZ group, and with Hyundai to advance planning the construction of SMR-160s in the Czech Republic.[61] In December 2022, Holtec applied to the British government for its design to undergo the GDA process carried out by the UK safety regulator, ONR.[62] By July 2023, the UK government had not published its response to the request. Holtec has begun a pre-application process with the US NRC prior to applying for design certification.[63]

56. Breakthrough for NuScale Power: Increase in Its SMR Output Delivers Customers 20 Percent More Power. Online. In: NuScale. 8. 6. 2018. *https://tinyurl.com/2fzhp63k*

57. NuScale Partners with ČEZ to Explore SMR Deployment in the Czech Republic. Online. In: NuScale. 26. 9. 2019. *https://tinyurl.com/x67zktrw*

58. About Us. Online. In: Holtec International. *https://tinyurl.com/32jre7y7*

59. Pre-Licensing Vendor Design Review. Online. In: Canadian Nuclear Safety Commission. Updated 20. 4. 2023. *https://tinyurl.com/mw3fr9bx*

60, 61. Holtec Advances Project Delivery Plan for SMR-160 in Czech Republic. Online. In: Holtec International. 25. 10. 2022. *https://tinyurl.com/3uc5rpud*

62. Holtec Britain Applies to Join UK Government Process for Generic Design Assessment of US-Origin SMR-160 Nuclear Reactor in the United Kingdom. Online. In: Holtec International. 19. 12. 2022. *https://tinyurl.com/y5pfrk7c*

63. SMR Pre-Application Activities. Online. In: United States Nuclear Regulatory Commission. Updated 30. 8. 2023. *https://tinyurl.com/2tfsxdxc*

5.4 Rolls-Royce SMR

The Rolls-Royce design was announced in 2017 with few design details revealed. Rolls-Royce tries to make a virtue of its admission that the design is just a conventional PWR. Rolls-Royce SMR's CEO, Tom Samson, told a UK parliamentary select committee '…we do not need a prototype. This is a standard pressurised water reactor… There is no innovation in the nuclear technology part.'[64] Initially it was said the design would produce 220-440MW, then 440MW was chosen, and in May 2021 it was uprated to 470MW, more than 50% larger than the normal upper limit for SMR designs.[65]

In evidence to a UK parliamentary select committee, the cost and risk of getting from a conceptual design to a saleable design was made clear in the conditions which Rolls-Royce demanded the government meet if they were to proceed with the design. These included [66]:

- **Match funding (at a minimum) up to the end of the licensing phase**
- **A GDA slot**
- **A suitable site to develop a First-of-a-Kind**
- **A guaranteed UK electricity market of 7GW [16 reactors]**

Rolls-Royce also asked that only one SMR technology be pursued in the UK and that, if an overseas technology was chosen instead of the Rolls-Royce design, Rolls-Royce should be the UK partner. Realistically, a guarantee of 7GW of reactor orders could only be given by the British government for reactors that would be owned by them. Agreeing to these conditions would represent an extraordinary gamble of public money on a design that is still in its infancy. In November 2020, the government allocated £18m, matched by the Rolls-Royce consortium, to develop a concept design. This phase was oncluded a year later, when the project moved to a second phase to further develop the concept reactor design enough to begin the GDA process. That phase was backed by a £210m grant from the government matched by £250m from private sector investors. In April 2022, the government instructed the nuclear regulator, the ONR, to begin the GDA. Phase 1 of the three phases of the GDA was completed in April 2023.[67] While the limited funding provided by the government has kept the project going so far, it represents just a small fraction of the cash needed to bring the design to commercial status. The government will be increasingly unwilling to commit more money to the technology while its economic and technical viability remains unproven, while the Rolls-Royce-led investors will be reluctant to commit more of their own funds unless there is a guaranteed market.[68]

Rolls-Royce appears to have recognised the implausibility of its demands and was reported to be requiring guarantees from the government for just four orders, claiming it could supplement this with export orders.[69] It is hard to believe that export customers would place orders before the technology has been fully demonstrated in the UK. Rolls-Royce has stated it would produce the first reactors using production line manufacture

64. Corrected oral evidence: UK energy supply and investment. Online. In: House of Lords, Economic Affairs Committee. 5. 4. 2022. *https://committees.parliament.uk/oralevidence/10083/html/*

65. UK SMR unveils new design and power. Online. In: Nuclear AMRC. 17. 5. 2021. *https://namrc.co.uk/industry/uk-smr-new-design/*

66. THOMAS, Steve, DORFMAN, Paul, MORRIS, Sean, RAMANA, M. V. Prospects for Small Modular Reactors in the UK & Worldwide. Online. In: Nuclear Consulting Group. 2019. *https://tinyurl.com/583r2tpa*

67. Step 1 GDA statement for the Rolls-Royce SMR. Online. In: Office for Nuclear Regulation. 3. 4. 2023. *https://www.onr.org.uk/new-reactors/rolls-royce/step-1-statement-of-findings.htm*

68. LORIMER, Kerry. Treasury red tape blamed for delay in SMR rollout. Online. In: Construction News. 9. 9. 2022. *https://tinyurl.com/mn2bmkkk*

69, 70. Corrected oral evidence: UK energy supply and investment. Online. In: House of Lords, Economic Affairs Committee. 5. 4. 2022. *https://tinyurl.com/5485rx4s* for the components and that its factories would produce two or four units per year.[70] This would imply that from the time the production lines started up to perhaps the first year or two of operation with the first unit (assuming a five-year construction period), if the production line was not closed or mothballed, components for 12 or more reactors would be completed. Rolls-Royce claims there is no need for a prototype (or demonstration) plant: 'We do not need a prototype. This is a standard pressurised water reactor...' and '...no innovation in the nuclear technology part.'[71] This is not convincing. The design is a new one, and while the components may have been successfully used in other designs or applications, it is how they work in combination that is the key issue. If the fact that it is a standard PWR was sufficient to guarantee its performance, there would be no need for a GDA.

Giving Rolls-Royce exclusive rights to the UK market was clearly not politically credible. Nevertheless, Rolls-Royce is ramping up its promotional effort aimed at convincing the public its reactor design is ready to go. Committing to this would release a bonanza of jobs, the company claims, at the construction sites,[72] and at the sites where the production lines would be installed, and would open up a large export market.[73]

While Rolls-Royce is widely seen as having nuclear expertise through its supply of submarine reactors, this is a very different technology, and the reactors supplied by Rolls-Royce use a US design (its own design having been rejected). So Rolls-Royce has limited experience in designing a submarine reactor that would actually be ordered.

In July 2023, the UK government announced major new funding of £157m for SMRs,[74] but this was all focused on so-called Advanced Modular Reactors. In the same statement, it announced the creation of a government-owned company, Great British Nuclear, whose main initial task would be to carry out a competition to identify the best SMR design(s) for the UK and to assist the winning design(s) to reach a Final Investment Decision in 2029.[75] No mention of Rolls-Royce was made in the announcement, nor did any of the press reports of the decision mention Rolls-Royce. This seems to imply that Rolls-Royce is not the front-runner for the UK, as it has previously been seen. It also suggests that Rolls-Royce's claims that a reactor could be in operation in the UK by 2029 are unrealistic.[76]

In January 2023, a new CEO, Tufan Erginbilgic, was appointed for Rolls-Royce promising a dramatic restructuring of the business, and he stated: 'We underperform every key competitor out there.'[77] Given the continuing absence of a commitment from the British government to provide the guaranteed orders the SMR needs for it to be taken forward, the SMR business is seen as a likely candidate to be axed.[78]

In November 2020, Rolls-Royce and ČEZ signed a Memorandum of Understanding to explore the potential for Rolls-Royce SMRs to be built in the Czech Republic.[79]

71. Corrected oral evidence: UK energy supply and investment. Online. In: House of Lords, Economic Affairs Committee. 5. 4. 2022. *https://committees.parliament.uk/oralevidence/10083/html/*

72. GOULD, Dan. Rolls-Royce SMR prioritises four NDA sites for 15 GW of new nuclear power. Online. In: Rolls-Royce Small Modular Reactors. 9. 11. 2022. *https://tinyurl.com/5n7enyxe*

73. GOULD, Dan. Final shortlist announced for first Rolls-Royce SMR factory. Online. In: Rolls-Royce Small Modular Reactors. 19. 12. 2022. *https://tinyurl.com/tcyffwuv*

74. British nuclear revival to move towards energy independence. Online. In: GOV.UK. 18. 7. 2023. *https://tinyurl.com/mr275emz*

75. Small Modular Reactors: competitive technology selection process. Online. In: GOV.UK. 18. 7. 2023. *https://tinyurl.com/3swz48c9*

76. FARMER, Matt. Rolls Royce plans first UK modular nuclear reactor for 2029. Online. In: Power Technology. 19. 4. 2022. *https://tinyurl.com/56zffzyu*

77. SWENEY, Mark. Rolls-Royce is a 'burning platform' that must transform, says new CEO. Online. In: The Guardian. 27. 1. 2023. *https://tinyurl.com/3tu5utvr*

78. MUSTOE, Howard. The 'ruthless' axeman carving out a new future for Rolls-Royce. In: The Telegraph. 28. 5. 2023. *https://tinyurl.com/5bhh96w4*

79. TODD, Ben. ROLLS-ROYCE SIGNS MOU WITH CEZ FOR COMPACT NUCLEAR POWER STATIONS. Online. In: ČEZ Group. 9. 11. 2020. *https://tinyurl.com/5xppnu8k*

5.5 Nuward

The Nuward nuclear power plant would comprise two reactors of 170MW. It was announced in 2019 and would be supplied by a subsidiary of Electricité de France (EDF), Framatome.[80] The two reactors would be housed in a single building sharing some equipment and the reactor would be submerged in a pool filled with water. Framatome claims it would be targeted at 'supplying electricity to remote areas or small-scale grids'. However, by the end of 2022, the design was still in the conceptual phase, with the basic design work to be carried out between 2023 and 2025. Detailed design work and licensing for it would be done between 2025 and 2030, and construction of a reference plant would start in 2030. No projected completion date is yet given. The publicity for the design mentions the usual list of SMR attributes, such as modular construction, standardisation, passive safety, and factory mass production of components. However, given the plan to build a demonstration plant in France before marketing the design, this would imply the components for the demonstration plant would not be made on production lines, so the economics of the series-built reactors would not be known.

In June 2022, EDF announced that a joint safety review would be carried out by the French (ASN), Czech (SUJB) and Finnish (STUK) safety regulators.[81] EDF has also concluded a memorandum of cooperation with ČEZ and, through its subsidiary ÚJV Řež, is ready to participate in the development.[82]

5.6 KAERI SMART

The SMART (System-integrated Modular Advanced ReacTor) has been under development by the Korea Atomic Energy Research Institute (KAERI) since 1997.[83] It is a 100MW PWR. In 2014, it was transferred to a new company, SMART power Co. Ltd., and in 2015, a Memorandum of Understanding (MOU) was signed with the King Abdullah City for Atomic and Renewable Energy (KA-CARE) with a view to constructing the first two SMART reactors in Saudi Arabia. These reactors would also be designed to provide desalination services.

Since 2015, progress has been slow. The basic design is said to be complete, but development has stalled due to the absence of any orders for an initial reference unit. The design received standard design approval from the Korean regulator in mid-2012, but given the early stage of development of the design, this is clearly only approval in principle, not approval to build a plant.[84] In April 2023, KAERI signed an MOU with the Alberta (Canada) government to collaborate on the deployment of SMART technology in Alberta, specifically for processing tar sands.[85] There appear to be no plans to build the design in Korea. There seems to be little interest outside Saudi Arabia in the SMART design and progress there is very slow, so the SMART design does not appear to be a major option. It would appear to be a very risky step for Saudi Arabia's first power reactor order to be for a first-of-a-kind design, so unless another customer emerges, it is hard to see a commercial future for this design. ČEZ has signed a memorandum of cooperation with KHNP to participate in development of the SMART.[86]

80. NUWARD™ SMR, leading the way to a low carbon world. Online. In: EDF.fr. *https://tinyurl.com/yc85cfrt*

81. European regulators to cooperate on Nuward SMR licensing. Online. In: World Nuclear News. 6. 6. 2022. *https://tinyurl.com/yc7c32kw*

82. KŘÍŽ, Ladislav. ČEZ after a preliminary assessment singled out two other preferred locations for small modular reactors, next to the Temelín pilot, they could to be established in Dětmarovice and Tušimice. Online. In: SKUPINA ČEZ. 27. 2. 2023. *https://tinyurl.com/44cew2am*

83. Development History. Online. In: Smart Power Co., Ltd. *http://www.smart-nuclear.com/tech/d_history.php*

84. Korea, Saudi Arabia progress with SMART collaboration. Online. In: World Nuclear News. 7. 1. 2020. *https://tinyurl.com/2wn82k7f*

85. MoU sees KAERI, Alberta cooperation on SMRs. Online. In: World Nuclear News. 20. 4. 2020. *https://tinyurl.com/mpcwwrbh*

86. South Bohemia Nuclear Park founded. Online. In: World Nuclear News. 1. 6. 2022. *https://tinyurl.com/yc6htycd*

5.7 Westinghouse AP300

Westinghouse has been reported as a potential supplier to the Czech Republic. It began development of a 225MW PWR design, but in 2014, it appeared to abandon the technology. It was a 225MW PWR on which development began around 2010 and was based on Westinghouse's large reactor, the AP1000 – a design certified by the US NRC in 2011. Since 2014, little further work has been done on the Westinghouse SMR. In February 2014, the CEO of Westinghouse stated: 'The problem I have with SMRs is not the technology, it's not the deployment – it's that there's no customers. The worst thing to do is get ahead of the market.'[87]

However, in May 2023, Westinghouse announced that it was developing a 300MW PWR, AP300, again based on a scaled-down version of its AP1000 design.[88] The design is not an integral one, but it does claim to rely solely on passive systems rather than systems that would have to be activated for protection against severe accidents. Whether passive systems offer more safety than active systems is not clear. The AP1000 also claims to be modular, in the sense of its major components being manufactured in factories, which means site-work just involves assembly.

The announcement contains some rather vague claims about the AP1000, for example, that it is setting performance records without specifying which ones. It glosses over the problems with the eight reactor orders that have been placed for the AP1000. The four orders for China were completed about six years late and 60% over-budget;[89] two orders for the USA (the Summer project) were abandoned after four years of construction because construction cost and schedule were out of control;[90] and two other orders for USA (Vogtle) are about 6 years late and about three times over-budget.[91] Westinghouse also claims six further AP1000s are under construction (the IAEA PRIS data base only lists four) but it appears this will use a Chinese version of the AP1000, CAP1000, and it is not clear what role, if any, Westinghouse will play in the construction of these plants.[92]

On May 9, Westinghouse announced that it had submitted a pre-application Regulatory Engagement Plan to the US NRC claiming the design could be certified by 2027.[93] It is not clear how long it would take from submission of this plan to the actual start of the review. The six designs that have completed the US design certification process took 5-9 years to complete the review. The AP1000 was based on the AP600, which received approval in 1998 after six years. In 2002, when Westinghouse submitted the AP1000 for NRC review, it claimed the process would take little more than a year because the AP1000 was just a scaled-up version of the AP600. In fact, the AP1000 only received final certification from the NRC in 2011. The claim of certification in 2027 appears extremely optimistic, therefore.

There must be major question marks about when the design will be available to order, assuming the Czech Republic is not willing to place an order until the design has undergone a comprehensive safety review. Nevertheless, ČEZ has signed a memorandum of cooperation with Westinghouse for the AP300.[94]

87. Pittsburgh Post Gazette „Westinghouse backs off small nuclear plants". 2. 1. 2014

88. AP 300™ SMR. Only SMR Based on Deployed, Operating & Advanced Reactor Technology. Online. In: Westinghouse Nucluear. *https://www.westinghousenuclear.com/energy-systems/ap300-smr*

89. DALTON, David. China's Sanmen-1 Becomes World's First AP1000 Reactor To Begin Commercial Operation. Online. In: The Independent Nuclear News Agency. 21. 9. 2018. *https://tinyurl.com/22j94244* Nuclear Power in China. Online. In: World Nuclear Association. *https://tinyurl.com/2xdw2bax*

90. REUTERS. Factbox: U.S. nuclear reactors that were canceled after construction began. Online. In: Reuters.com. 31. 7. 2017. *https://tinyurl.com/jzpsb63v*

91. COOKE, Stephanie. Newbuild: How Much of Vogtle's Capital Costs Can Southern Recover? Online. 28. 4. 2023. *https://tinyurl.com/bddp5v5x*

92. Nuclear Power in China. Online. In: World Nuclear Association. *https://tinyurl.com/2xdw2bax*

93. Westinghouse Submits AP300™ SMR Regulatory Engagement Plan to Nuclear Regulatory Commission. Online. In: Westinghouse. 9. 5. 2023. *https://tinyurl.com/ybctz3un*

94. Czechia's ČEZ plans SMRs at two coal-fired power plants sites. Online. In: Enerdata. 28. 2. 2023. *https://tinyurl.com/5n6mp9ze*

6. Are the claims for SMRs credible?

At best, the claims for SMRs are untested and, given that no commercial order for an SMR has been placed yet, much less built and put into operation, it will be a decade or more before there is any evidence to test these claims. The history of nuclear power is one of claims that sound intuitively reasonable not being realised in practice. These include claims that standardisation, learning by doing, and technology change would reduce costs and improve performance. In fact, the real cost of nuclear power plants has only ever gone up over the six-decade commercial history of nuclear power and continues to rise. More pertinently, reactors have increased in size because of plausible claims that scale economies would reduce costs.

One analysis of the potential costs of power from SMRs suggests that none of the designs it examined would be competitive with renewable technologies.[95] This analysis included all the SMR designs under consideration for the Czech Republic except the Westinghouse AP300, which had not been announced when the analysis was carried out. A former Commissioner at the US NRC, Alison MacFarlane, has also been sceptical about the claims made for SMRs.[96] Professor MacFarlane also co-authored a paper that claimed SMRs will inevitably produce more radioactive waste than large reactors.[97]

95. STEIGERWALD Björn et al. „Uncertainties in Estimating Production Costs, of Future Nuclear Technologies: A Model-based Analysis of Small Modular Reactors". Energy. 2023, n. 281

96. MacFARLANE, Allison. The end of Oppenheimer's energy dream. In: IAI News. 21. 7. 2023. *https://tinyurl.com/422kke2b*

97. KRALL, Lindsay M. „Nuclear waste from small modular reactors". PNAS. 2022, vol 119, n. 23, p. 1- 12

6.1 Production-line manufacture of components

The assumption is that production-line manufacture will allow for better, more assured quality and lower prices. The terminology gives the image of a moving production line as used, for example, to make cars, producing large numbers of components, but this is misleading. The number of orders will be relatively small; for example, Rolls-Royce expects its production lines to produce equipment for just two reactors per year. Even at the height of reactor ordering in France, only about six reactors per year were being produced. There appears to be no reason why quality on a production line should necessarily be better, especially with such small numbers of orders. This will depend on the rigour of quality control procedures. There might be savings in terms of costs compared to traditional fabrication methods, provided a large number of reactors are ordered, but this will be offset by the cost of developing and equipping the production lines. It also seems unlikely the reactors will be produced on one production line; the components are more likely to be manufactured at different facilities, then assembled into larger modules at a central site before full assembly at the actual reactor site.

Production lines would also reduce flexibility and might risk standardised error. Once the production line is in place, it needs a flow of orders if it is to be maintained in operation, and if this does not materialise, the facility will either have to be mothballed or closed. If identical components are produced on the production line, there is a risk that if a design flaw emerges later, this flaw will be replicated on all plants produced using the production line. This risk is being clearly illustrated in France, where a large number of reactors were off-line in winter of 2022-23 because of concerns about their safety due to stress corrosion cracking.[98]

98. Stress corrosion phenomenon detected on Civaux 1 and 2, Chooz B2 and Penly 1 reactors. Online. In: ASN. 31. 1. 2022. *https://tinyurl.com/mrx3hpzs*

6.2 Scale economies

The reason reactors have increased in size from the original reactors of 150-300MW is the pursuit of scale economies and the intuitive belief that, for example, a reactor of 1000MW will be less than twice as expensive as a reactor of 500MW. These scale economies have been difficult to observe in practice. This may be because scale economies have been more than counter-balanced by other factors, such as increased safety requirements or diseconomies of scale, such as greater difficulty in managing larger projects efficiently.

However, a scaled-down reactor is, all things being equal, likely to cost more per kW of capacity than a large one. For example, a 500MW reactor vessel will cost more than 50% of the cost of the same items for a 1000MW reactor. It is notable that the NuScale design has more than doubled in output (35MW to 77MW) since it was first proposed, and the Rolls-Royce design has already increased from 440MW to 470MW, presumably in pursuit of scale economies; Rolls-Royce now talks about 500MW reactors.[99] The Westinghouse AP600 design, which received regulatory approval, was abandoned because it was uneconomic, and was then scaled up to the AP1000. In China, which is building its own version of the AP1000, the CAP1000, it has scaled the design up to 1500MW (the CAP1500, which it claims would be its own intellectual property) again, presumably in pursuit of scale economies. So, scaling down the reactor seems unlikely to do anything but increase the cost per unit of capacity.

6.3 Modular components

The claim is that delays and cost escalation at nuclear projects are in part due to the large amount of on-site fitting required. On-site work is said to be more difficult to manage effectively than factory work. Again, the rhetoric implying reactors will arrive on site in 'flat-packs' which just requiring bolting together is misleading. Reactors will still require large foundations and electrical and water services. The AP1000 is claimed to be modular in this sense, but that did not prevent the four AP1000s built in China being six years late and about 60% over-budget. Of the two projects in the USA using AP1000 technology, one had to be abandoned because costs and times were out of control, while the other is about six years late and about three times over-budget. Modular construction is therefore clearly no guarantee that cost-escalation and delays will not occur.

99. Corrected oral evidence: UK energy supply and investment. Online. In: House of Lords, Economic Affairs Committee. 5. 4. 2022. *https://committees.parliament.uk/oralevidence/10083/html/*

6.4 Quicker construction and less risk of delay

Claims that construction will happen faster with less risk of delay seem intuitively reasonable but are, at best, untested. If the problem is the sheer scale of large reactors, then small reactors might be easier to build than large ones. However, if their complexity is the problem, it is not clear why SMRs should be less complex than large reactors and therefore any less prone to delays and cost increases.

6.5 Easier finance

SMR proponents claim financing will be easier for SMRs than large reactors on two grounds. First, because they will be cheaper per reactor, the sum needed will be smaller and would be easier to raise. Second, if the record of building on time and at cost for SMRs is better than for large reactors, the perceived investment risk will be less, and financiers will be more willing to lend money to nuclear projects. The claim of easier financing, therefore, depends largely on SMRs having a better record of construction than large reactors. This will not be established until and if there are a significant number of SMRs operating, perhaps in 20 years.

6.6 Incremental addition of capacity

The incremental addition of capacity is a characteristic that was originally prominent in the PR for SMRs, the idea that for small grids, reactors could be added at the same site incrementally as electricity demand required additional capacity. It does not seem to be a major selling point for any of the designs under consideration in the Czech Republic.

7. Issues to be faced

7.1 Siting

The output of the proposed SMRs seems to be increasing, with the most likely candidates for the Czech Republic now at or beyond 300MW. This makes them about the same size as the reactors installed at the Dukovany site. Given the difficulty of getting public consent to open new reactor sites, new reactors are increasingly being proposed for sites which have already housed reactors. Failing that, they might be sited at locations of existing large power plants, especially coal-fired plants. For SMRs, either a significant number of new sites will be needed to achieve the capacity a single large reactor would provide, or multiple reactors would be built at the same site. If the latter were chosen, this would make the capacity on one site effectively as large as that provided by one large reactor.

7.2 Safety requirements

An issue that SMR developers do not address is whether they expect the requirements in terms of safety systems to be comparable to those required for large reactors. For example, large reactors now are required to include a system that, in a melt-down accident, will prevent the core from getting into the surrounding environment, for example, a 'core-catcher'. Would such systems be required for SMRs? Would the emergency planning zone be smaller? The upward creep in the size of SMRs means that the difference between them and large reactors is getting smaller and, for example, the operating reactors at Dukovany have a similar level of output to most of the designs. They are also comparable in size to the Fukushima 1 reactor that melted down in 2011. Given the damage this caused, it seems logical that the safety requirements for SMRs should be no less rigorous than those applied to large reactors.

8. Conclusions

There is an avalanche of publicity for SMRs creating the impression that the technology is taking off, with a large number of orders being placed. ČEZ and its subsidiaries, including Škoda Praha, have signed cooperation agreements with the suppliers of all the SMR designs under consideration for the Czech Republic. If these agreements require substantive efforts on the part of ČEZ, this represents a major commitment of resources to a large number of designs, which may prove fruitless if SMRs are not pursued in the Czech Republic. It is more likely these are primarily symbolic agreements which do not represent a major capability in ČEZ on these designs.

Worldwide, there are few SMRs under construction, and none are commercial designs (see Table 3). Press reports frequently state hopes for the reactors as if they were established facts, not just untested claims; for example, they state SMRs are cheaper and safer than large reactors. Nevertheless, the amount of publicity and the lack of prospects for large reactor orders has provoked the large traditional reactor vendors in the USA and Europe (GE-Hitachi, Westinghouse and Framatome) to enter the field. These have more credibility than their competitors, who are often small companies with no previous experience of designing and supplying a nuclear power plant. However, in the case of GE-Hitachi and Westinghouse, the SMR designs are based on scaled-down versions of large designs that have proved hopelessly uneconomic. The Framatome design is new, only being announced in 2019, and was still at the concept stage in 2022; it is not planned to be commercially available until after 2030.

The reality is that not only has no commercial order for an SMR been placed yet, but also no design being offered has completed a comprehensive safety evaluation by an experienced, independent safety regulatory body. The claims for SMRs are, therefore, no more than speculative and unproven. All experience with nuclear technology suggests there is a high probability these claims will not be substantiated, and no more than a handful of orders will be placed before the technologies are abandoned and the nuclear industry moves on to its next new technology. Under George W. Bush Nuclear 2010, 33 reactor projects were announced, but just four turned into firm orders, with two of the four being abandoned in mid-construction. In the UK, the programme announced by Tony Blair in 2008 was expected to lead to 16GW of new nuclear capacity being online by 2030. Only one project (3GW) went forward, and any further delays with it are likely to mean itwill not be complete by 2030.

Table 2: SMR designs under consideration in Czech Republic

VENDOR	TYPE	SIZE (MWE)	YEAR PUBLICISED	OTHER COUNTRIES INTERESTED	SAFETY CHECK IN PRINCIPLE	SAFETY CHECK IN DETAIL
GE-Hitachi BWRX-300	BWR	300	2018	USA, Canada, Estonia, Poland	Canada	Applied for UK GDA 12/22
NuScale	PWR	77	2007	USA	Canada 60MW	USA 50MW completed in 2021
Holtec SMR-160	PWR	160	2010	—	Canada	Applied for UK GDA 12/22
Rolls Royce SMR	PWR	470	2017	UK	—	UK process started in 2022
Nuward	PWR	2×170	2019	France	—	—
KAERI SMART	PWR	100	1997	Korea, Saudi Arabia	Korea	—
Westinghouse SMR	PWR	300	2023	—	—	—

Source: Author's research

Table 3: SMRs under construction or in operation

ZEMĚ	MÍSTO	MODEL	TYP	VELIKOST (MWE)	ZAČÁTEK VÝSTAVBY	ZAHÁJENÍ KOMERČNÍHO PROVOZU
Argentina	Zarate	CAREM25	PWR	25	8/2015	—
China	Linglong 1	ACP100	PWR	100	7/2021	—
China	Shidao Bay	HTR-PM	HTGR	200	12/2012	—
Russia	Lomonosov 1 a 2	KLT40S	PWR	2×32	4/2007	5/2020
Russia	Brest	OD300	SFR	300	6/2021	—

Source: https://pris.iaea.org/PRIS/home.aspx
Shidao Bay went critical in September 2021, but by July 2023 it was not shown as being in commercial operation in the IAEA PRIS database and in 2022, it produced no power [100].

100. China Nuclear Energy Association. *https://tinyurl.com/y97k5xmd*

SMRs and the Czech Republic

Edvard Sequens

Prof. Thomas' report covered all seven designs of small and medium-sized modular reactors under consideration by energy provider ČEZ for use in the Czech Republic. In recent years, the ČEZ group has signed memoranda of cooperation for SMRs with NuScale, GE Hitachi, Rolls Royce, EdF, Westinghouse, KHNP, and Holtec.[101] Czech and UK ministers have also signed a joint statement on cooperation for the development and application of small and medium-sized nuclear reactors (SMRs.[102] ČEZ aims to select one of the technologies as early as 2024, regardless of whether the vendor secures a licence in its country of origin.[103]

Meanwhile, CEZ has been preparing its first SMR site, in close proximity to the Temelín nuclear plant, aiming to launch the inaugural SMR of the chosen design in the country by 2032.[104] From a power-grid perspective, adding a new small source in this location makes no sense, given that the two large Temelín reactors cover the electricity needs of the South Bohemia region fivefold. However, with the existing infrastructure and no apparent hurdles, the company is keen on launching a pilot testing site for the new technology here. According to ČEZ's vision, the new reactor should become a training facility for operators—both Czech and international—for upcoming SMRs of the same type. In 2022, the 'South-Bohemian Nuclear Park' project was presented and a limited-liability company South Bohemian Nuclear Park s.r.o. established. ČEZ holds a direct capital interest of 40%, with another 40% in the hands of the South Bohemia region and the remaining 20% held by UJV Rez a.s.[105] As laid out, South Bohemia Nuclear Park s.r.o. administers research, development, and pilot project preparation.

To potentially set up additional SMRs, ČEZ has identified sites in Tušimice and Detmarovice, considering the replacement of existing coal plants with new SMRs. The company plans to conduct thorough surveys at these locations, while already exploring other coal plant sites, along with the Dukovany nuclear plant site.[106]

In the Czech Republic, there have been announcements about the development of various local SMR designs, ranging from third-generation to advanced technologies (see Table 4). PR statements associated with some of these projects create an impression of technological readiness that does not align with reality. The primary objective appears to be securing substantial public funding for research and development. In reality, investors, particularly ČEZ, currently have no plans to incorporate Czech designs into the country's own power grid.

101. SVITÁK, Marek. „Kraj, ČEZ a ÚJV Řež zakládají Jihočeský jaderný park. Projekt má urychlit přípravu a zavádění malých modulárních reaktorů v České republice." Online. In: SKUPINA ČEZ. 30. 5. 2022. [in Czech] *https://tinyurl.com/5b7tykdh*

102. „Česká republika bude spolupracovat s Velkou Británií na vývoji malých a středních jaderných reaktorů." Online. In: Ministerstvo průmyslu a obchodu. 11. 9. 2023. *https://tinyurl.com/5fb8pun7*

103. Confirmed by a ČEZ representative at the company's General Assembly on 26 June 2023.

104. „ČEZ chce stavět malé modulární reaktory v Temelíně, Dukovanech nebo Mělníku. První bude v roce 2032." Online. In: iRozhlas. 15. 2. 2023. [in Czech] *https://tinyurl.com/je4chsmn*

105. The South-Bohemian Nuclear Park. Online. In: SKUPINA ČEZ. *https://tinyurl.com/f2h5wph7*

106. KŘÍŽ, Ladislav. „After preliminary assessment ČEZ has identified two preferred construction sites for small modular reactors, in addition to the Temelín pilot location, in Dětmarovice and Tušimice." Online. In: Skupina ČEZ. 27 February 2023. *https://tinyurl.com/mybk2p56*

CR–100

This light-water PWR design was announced by *Centrum výzkumu Řěž*, a member of the CEZ group, in 2021. The design is based on operating Soviet-type VVER reactors, with a specific plan to use shortened fuel utilised in the Temelín reactors. As the cogenerating unit would produce 9 MWe and 72 MWt, it is presented as a suitable replacement for central heating sources in municipalities or for use in hydrogen production. According to the designers, safety is anchored in its low power, enabling the dissipation of residual heat without the need for additional passive safety systems.[107]

DAVID

The developers of the DAVID SMR have adopted a similar approach, drawing from VVER reactors and incorporating the shortened fuel used in VVER-1000 reactors and supplied by Westinghouse. This design would have an installed capacity of 50 MWe or 175 MWt, allowing for the potential clustering of up to eight units at a single site. Initially announced by the engineering group Witkowitz in 2021, the project is currently administered by Witkowitz Atomica a.s.,[108] with design assistance from Czechatom a.s.[109] Developers from Ukraine are also actively involved, and there is potential for using this design in Ukraine, as indicated.

TEPLATOR

The TEPLATOR SMR, strongly promoted since its initial announcement by scientists from CTU and the University of West Bohemia in 2020, is specifically tailored for applications in the heating industry. Drawing inspiration from CANDU reactors, this heavy-water design is projected to produce 50–150 MWt. Unlike CANDU, however, it has the capability to utilise the residual energy from spent fuel of light-water VVER-440 reactors. However, this has sparked big concerns about nuclear safety and licensing issues, leading the developers to consider the use of fresh fuel. Facing a negative reception from Czech nuclear energy experts, the promoters of the design, currently operating through Teplator a.s., have shifted their focus to Ukraine, revealing plans for the preparation of their first operating prototype. Additionally, they aim to secure a licence in Canada or France by 2024.[110]

Energy Well

Centum výzkumu Řež has been developing its own advanced SMR, named Energy Well, since its initial announcement in 2018. This molten salt reactor design, utilising a coolant mixture of lithium fluoride and beryllium fluoride and fuelled by spherical TRISO particles, is projected to generate 20 MWt and up to 8 MWe. Currently, the team is said to be focused on constructing an experimental unit to evaluate the fundamental physical attributes of the system. Their goal is to have a fully functional reactor within the next ten years, contingent on securing sufficient financial support, amounting to billions of CZK.[111]

107. „Malý modulární reaktor CR-100. Online. In: CR-100.cz." [in Czech] *https://cr100.cz/*

108. „David SMR." Online. In: Witkowitz Atoma. *https://witkowitz-atomica.com/david-smr-presentation*

109. „About Us." Online. In: CZECHATOM. *https://czechatom.com*

110. „Inovační technologie Teplator." Online. In: Teplator. *https://www.teplator.cz/?lang=en*

111. „Energy Well. Online." In: Energywell.cz. *https://www.energywell.cz/*

HeFASTo

Another Czech SMR prototype, HeFASTo, has been in development at ÚJV Řež since 2021. Technologically, it is an advanced helium-cooled fast reactor designed to operate at high temperatures—with an outlet temperature from the core expected to reach 900°C. This makes it desirable for hydrogen production or chemical industry applications. The total thermal output is projected to be 200 MWt. The project team is now seeking a strategic partner with the vision of bringing this reactor into commercial operation by 2040.[112]

In the Czech Republic, the idea of SMRs being the future of nuclear power is gaining traction among politicians, journalists, and subsequently the public. However, the first CVVM public opinion poll on SMRs conducted in June 2020 [113] indicated that there was not strong public support. Only slightly more than a quarter (28%) of respondents would find it acceptable to have an SMR built within 10 km of their home. In contrast, a majority (55%) would deem it unacceptable, with 29% even considering it 'definitely unacceptable.'

The 'Czech SMR Roadmap – Applicability and Contribution to the Economy' is currently in the final stages of development.[114] Once approved by the government, it is intended to serve as a key input for the ongoing formulation of the country's new State Energy Policy. This policy aims to establish a mechanism for public financial support for SMRs and streamline the permitting and licensing processes for these technologies. It appears that obtaining licences under the Czech Atomic Act, historically based on experience with large LWRs, may not be any easier or quicker for SMRs. The question arises as to whether it should be, especially if the considered reactor types are of a similar size to the existing VVER-440 at Dukovany, with the additional consideration of their potential proximity to urban areas.

112. „HeFASTo – Concept of Advanced Modular Reactor for the Future." Online. In: ÚJV Řež, a. s. *https://www.ujv.cz/en/products-and-services-1/research-development/hefasto*

113. ČERVENKA, Jan – ĎURĎOVIČ, Martin. „Czech public opinion on small modular reactors – June 2020." Online. In: Centrum pro výzkum veřejného mínění. 3 December 2020. *https://tinyurl.com/4ma849ew*

114. „108/23 Plán pro malé a střední reaktory v ČR;T:4.7.2023." Online. In: Hospodářská komora České republiky. 23. 6. 2023. [in Czech] *https://tinyurl.com/3kkxma6b*

Table 4: SMRs in development in the Czech Republic, all currently in the conceptual design phase

MODEL	DEVELOPER/VENDOR	TECHNOLOGY	ELECTRICAL OUTPUT (MWE)	THERMAL OUTPUT (MWT)	YEAR PUBLICISED
CR-100	CV Řež / ČEZ	PWR	9	72	2021
DAVID	Witkowitz Atomica	PWR	50	175	2021
TEPLATOR	Teplator a.s.	PHWR	—	50–150	2020
Energy Well	CV Řež / ČEZ	FHR	8	20	2018
HeFASTo	CV Řež / ČEZ	GFR	—	200	2021

Prospects of Small Modular Reactors in the Czech Republic

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