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Part 1: Small Nuclear Reactors: How Hunger for Power Will Unite Artificial Intelligence and Uranium/ Thorium Mining. Scope and Promise

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"HALEU fuel will enable smaller designs, longer operating cycles and increased efficiencies (of SMR)," said Olena Mykolaichuk, Director of the Division of Nuclear Fuel Cycle and Waste Technology at the IAEA.

"The next generation of nuclear technologies will require new supply chains for new kinds of fuel. Efforts are now underway to build out those supply chains, but a lot more remains to be done, including demonstrating a clear business case for these advanced reactors in many regions, if we are to ensure the necessary supply of HALEU fuel. However, I'm confident that we can do that." Ki Seob Sim, Nuclear Fuel Engineering Specialist at the IAEA.

Abstract

Data center operators face two energy-related challenges in their quest to build greater data center capacity to meet demand: a shortage of available energy to power data centers and the need to reduce carbon emissions. But an emerging nuclear technology, Small Modular Reactors (SMRs), could solve both issues. When Amazon Web Services paid US $650 million in March for another data center to add to its armada, the tech giant looked for a steady supply of nuclear energy to power it. The Susquehanna Steam Electric Station outside of Berick, Pennsylvania, which generates 2.5 gigawatts of nuclear power, sits adjacent to the humming data center and has been directly powering it since the center opened in 2023. After striking the deal, Amazon wanted to change the terms of its original agreement to buy 180 megawatts of additional power directly from the nuclear plant. Susquehanna agreed to sell it. But third parties weren't happy about that, and their deal has become bogged down in a regulatory battle that will likely set a precedent for data centers, cryptocurrency mining operations, and other computing facilities with voracious appetites for clean electricity. Putting a data center right next to a power plant so that it can draw electricity from it directly, rather than from the grid, is becoming more common as data centers seek out cheap, steady, carbon-free power. Proposals for co-locating data centers next to nuclear power have popped up in the US and Europe. Sweden is considering using small modular reactors to power future data centers. However, co-location raises questions about equity and energy security because directly connected data centers can avoid paying fees that would otherwise help maintain grids. They also hog hundreds of megawatts that could be going elsewhere. But it is setting a trend. World over, uranium and thorium-based modular or small nuclear power reactors are being considered for AI data centers and cryptocurrency stations. The money chasing the deals is huge, and cross-continental collaborations are spawning. This is a space to watch, more so because the challenges are worth the opportunities. Many players are silently joining the game.

Keywords: *Data Center, Edge Computing, Market, Private Investment, Rack, Small Modular Reactor*

1.0 Introduction

Have you ever considered how Artificial Intelligence (AI) does hundreds and thousands of iterations in less than a second to give you an AI-based summary of what you ask in any browser like Google? To run iterations, the

AI machines understand, compute, and deliver using enormous power in a very short period, with a latency time of 1 ms.

The power is used up in a rack where all the processing takes place. A data center rack (Figure 1) is a framework that holds IT equipment, such as servers, cables, routers, and switches, in a data center or communications closet. Racks are typically made of steel and are made up of a series of shelves, or bays, stacked on top of each other. Servers, switches, routers and other IT hardware are arranged in open metal frames—racks, consisting of shelves or bays—for space and airflow optimization, reduction of cable clutter, easy access and easy maintenance. Finally, cabinets are enclosed structures providing security and environmental control with protection against unpermitted access, dust and physical damage. They are often used in data centers because they are cost-effective, space-efficient, and allow for easy access to equipment[1].

Racks can help with:

a. *Airflow*: Stacking servers in a rack makes it easier to control airflow and keep equipment cool.
b. *Wire organization*: Racks can help keep power, network, and other cables organized, making it easier to find the right wire and avoid damage.
c. *Access*: Racks make it easier to reach servers and remove and replace them.
d. *Security*: The enclosed metal structure of a rack protects the equipment inside from accidental contact, and door locks can prevent unauthorized access.

Racks are different from cabinets, which are enclosed structures that provide greater protection and security for IT equipment. Cabinets usually have doors that can be locked and side panels that provide additional protection. You measure data racks by a unit of measurement called "U," short for unit. One U is 1.75 inches tall. Most servers get built in 1.75-inch increments that translate to U's. Of course, rack heights vary, but they're usually between 42U and 52U tall.



Figure 1. A Data centre rack.



Figure 2. An AWS data center.

A DC consists of different units with specific roles (Figure 2). Servers, the backbone of such a system, handle the bulk of computational workload and data processing. They run applications and services such as email, gaming platforms and company software; manage network traffic; and host multiple virtual machines with the goal of optimising resources. Functionally, servers can be grouped into clusters to form a single system, providing redundancy and load balancing. Cooling systems keep optimal temperatures for servers and other gear that consume a lot of energy. Storage drives include hard drives and solid-state memory arrays and require substantial power to operate and ensure data integrity. Network devices are essentially made up of routers and switches for managing data traffic inside a single DC and/or between different DCs and are power-intensive, too. Whereas a router directs data between different networks—by assigning, for instance, an IP address for the best transfer path—a switch connects multiple devices within the same network[1-3].

2.0 The Rack Power Consumption

The average power consumption for a server rack is typically 7 kW; however, AI applications could use more than 30 kW per rack. The increase in kilowatts is required because AI needs greater processor utilization, such as applications running on GPU-type servers—they need twice as much power per chip. Data center power consumption varies depending on the size of the facility, the efficiency of the equipment, and the type of workloads it supports:

- **Traditional data centers** typically have 5–10 kilowatts (kW) of power per rack.
- **High-density data centers**: Average around 10 kW per rack.
- **Ultra high-density data centers**: Average around 85 kW per rack.
- **AI data centers**: Require 60 or more kW per rack due to the increased data storage and generation needs of AI applications.
- **Small data centers**: These usually consume 1–5 megawatts (MW) of power.

Of course, you can try to move data around if your facility is power-constrained, but this could require a lot more energy than it takes to process the data, and power drain is always linked to the volume of data in motion. Simply put, there is a high cost associated with data transfers.

For example, although there are many cloud providers (AWS, Azure, Google, *etc.*) to choose from, many companies experience a hidden cost associated with

complex data transfer prices. A plausible solution to this dilemma is not to move the data but to process it much closer to the point of origination—creating yet another need for edge computing.

Data center power consumption is expected to increase significantly in the coming years due to the growing demand for power-intensive workloads like AI and cryptocurrency mining. The International Energy Agency projects that data center energy consumption could increase to between 650–1,050 terawatt-hours (TWh) by 2026.

To reduce a data center's energy footprint, you can:

a. Optimize the cooling system to avoid overcooling.
b. Rearrange racks and cooling units to improve cooling efficiency.
c. Plan how new equipment will work with the cooling system to ensure proper airflow.
d. Implement energy efficiency initiatives[2-4].

3.0 Little Networks

Edge computing is poised to become the anchor of yet another ubiquitous and much-anticipated data advancement known as 5G. The 1 ms latency times expected from 5G require the support of many distributed processing zones (aka edge networks). Edge-based servers need to be located closer to individuals streaming 4K videos and eventually 8K formats, as well as applications such as cameras used to monitor pedestrian and traffic movements in smart cities—and this is all without sending it to the cloud (Figure 3).

In addition, edge networks will be required to support autonomous vehicles. At the heart of this elegant tapestry of new data streams will be AI processing information in near-real time.

For the time being, all AI applications run on silicon-based computational hardware, whether that is in a custom chip built into your smartphone, in an FPGA deployed inside an edge computing server, or in a purpose-built AI-focused system such as the DGX from Nvidia that is accessed through a public cloud.

And that hardware all requires power, be it DC (like a battery) or AC (from the grid). It also requires connectivity between physical systems, whether over copper or fiber data connections.

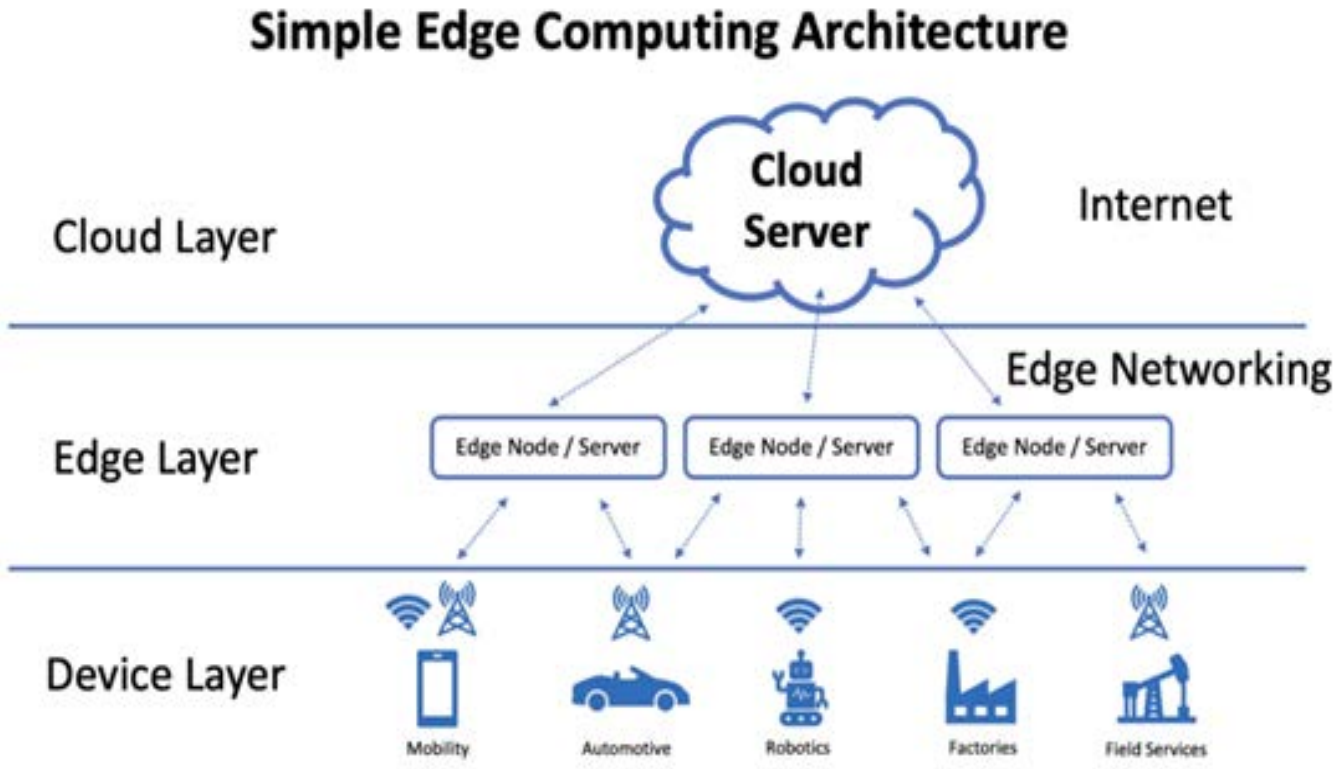


Figure 3. Edge computing architecture.

4.0 Speed and Scale

Energy demand for data centers has been growing 10 percent annually. AI accelerates this growth. Schneider Electric estimates that AI power consumption will grow at a rate of 25% to 33% annually through 2028, when it could reach as much as 18.7 gigawatts (GW), taking data center power consumption to 93 GW. Microsoft, Alphabet, Amazon, and Meta have market capitalizations of over $1 trillion each. They see the value of being the platform leader in AI as worth trillions. They want speed and scale in getting massive new data centers built, powered, and running.

5.0 Nuclear Power

Some data centers are powered by nuclear plants, and more are exploring the option:

Benefits

a. Nuclear power can be a reliable and cost-effective alternative to traditional energy sources:
b. Reduced environmental impact: Nuclear power plants don't emit greenhouse gases while operating.
c. Energy security: Nuclear power plants have less than 1% downtime, so critical functions remain unaffected during power outages.
d. Cost efficiency: Long-term operational cost savings can outweigh the upfront investment in nuclear power infrastructure.

6.0 Companies Exploring Nuclear Power

Tech giants like Amazon, Google, and Microsoft are exploring nuclear power for their data centers: In 2024, Amazon purchased a data center campus powered by a nuclear power plant from Talen Energy. Amazon is also investing in small nuclear reactors, Google is purchasing nuclear energy from Kairos Power. Google has also signed a deal to work with Nucor Corporation to help bring advanced nuclear projects online. Microsoft is buying energy from the Three Mile Island nuclear power plant. Microsoft is also searching for people to initiate plans for SMRs to power its data centers.

Other options: data centers can also benefit from co-locating with existing nuclear reactors. Small Modular Reactors (SMRs) are advanced nuclear reactors that have a power capacity of up to 300 MW(e) per unit. SMRs can eliminate the need to locate data center facilities near existing power plants.

7.0 Small Modular Reactors (SMRs)

SMRs are advanced nuclear reactors that have a power capacity of up to 300 MW(e) per unit, which is about one-third of the generating capacity of traditional nuclear power reactors (Figures 4, 5)[1-3]. SMRs, which can produce a large amount of low-carbon electricity, are:

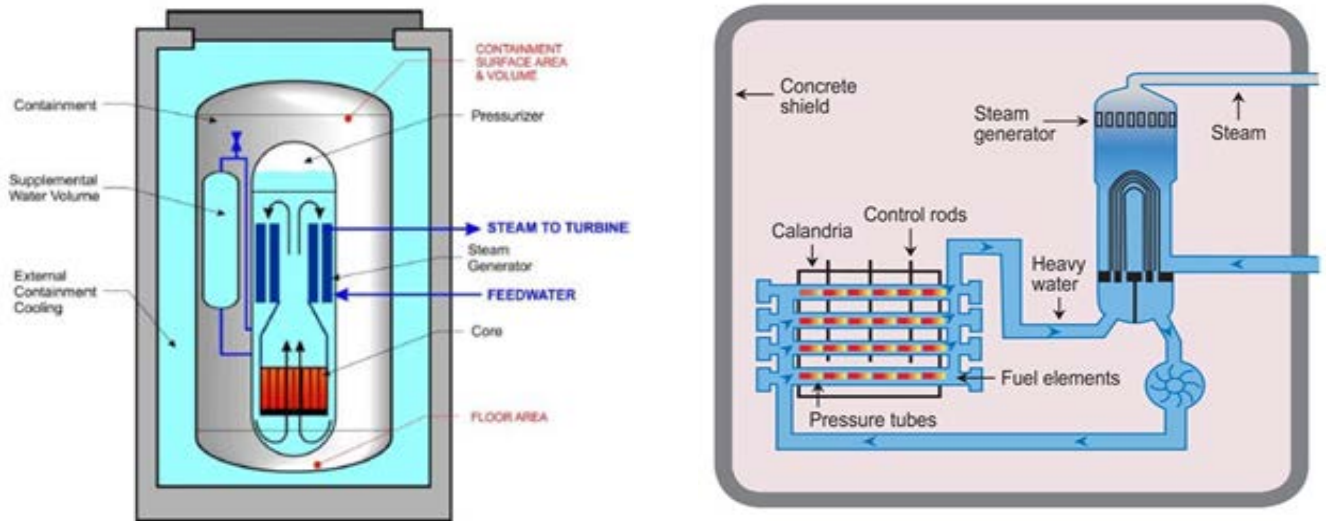


Figure 4. The schematics of small modular reactors.

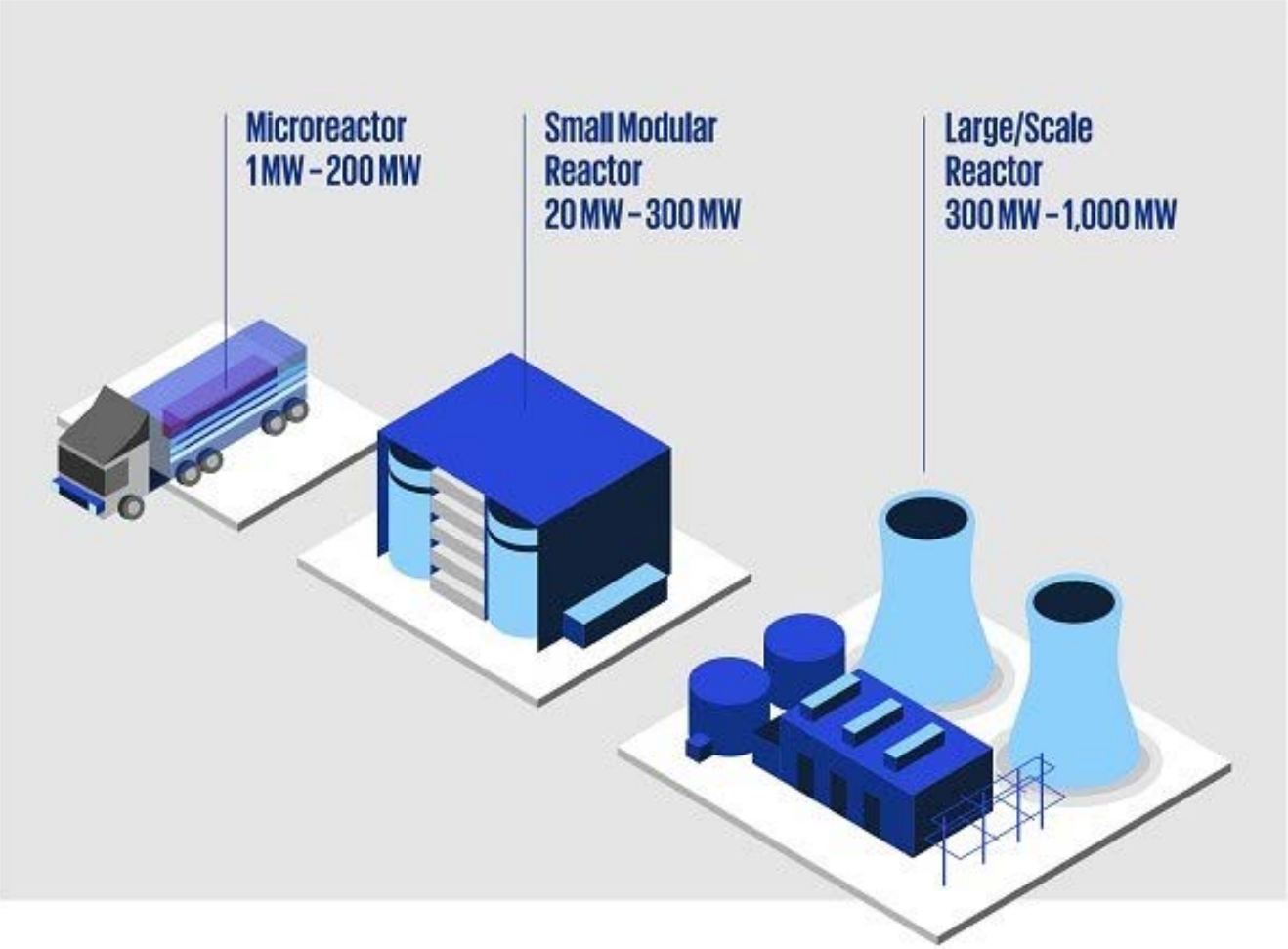


Figure 5. The concepts of small nuclear reactors.

a. *Small* – physically a fraction of the size of a conventional nuclear power reactor.
b. *Modular* – making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation.
c. *Reactors* – harnessing nuclear fission to generate heat to produce energy.

8.0 Oracle's Data Center Would be Powered by Three Small Nuclear Reactors

Oracle is looking to secure power from next-generation nuclear technology.

"Let me say something that's going to sound bizarre," Ellison, CEO, Oracle told analysts. "Well, you'd probably say, well, he says bizarre things all the time, so why is he announcing this one? It must be really bizarre." Oracle is designing a data center that will require more than a gigawatt of electricity, the company's chairman said. The data center would be powered by three small nuclear reactors, he added. Small modular nuclear reactors are new designs that promise to speed the deployment of reliable, carbon-free energy as power demand rises from data centers, manufacturing and the broader electrification of the economy (Figure 6).

Generally, these reactors are 300 megawatts or less, about a third the size of the typical reactor in the current U.S. fleet. They would be prefabricated in several pieces and then assembled on the site, reducing the capital



Figure 6. Oracle imagescape of the plan.

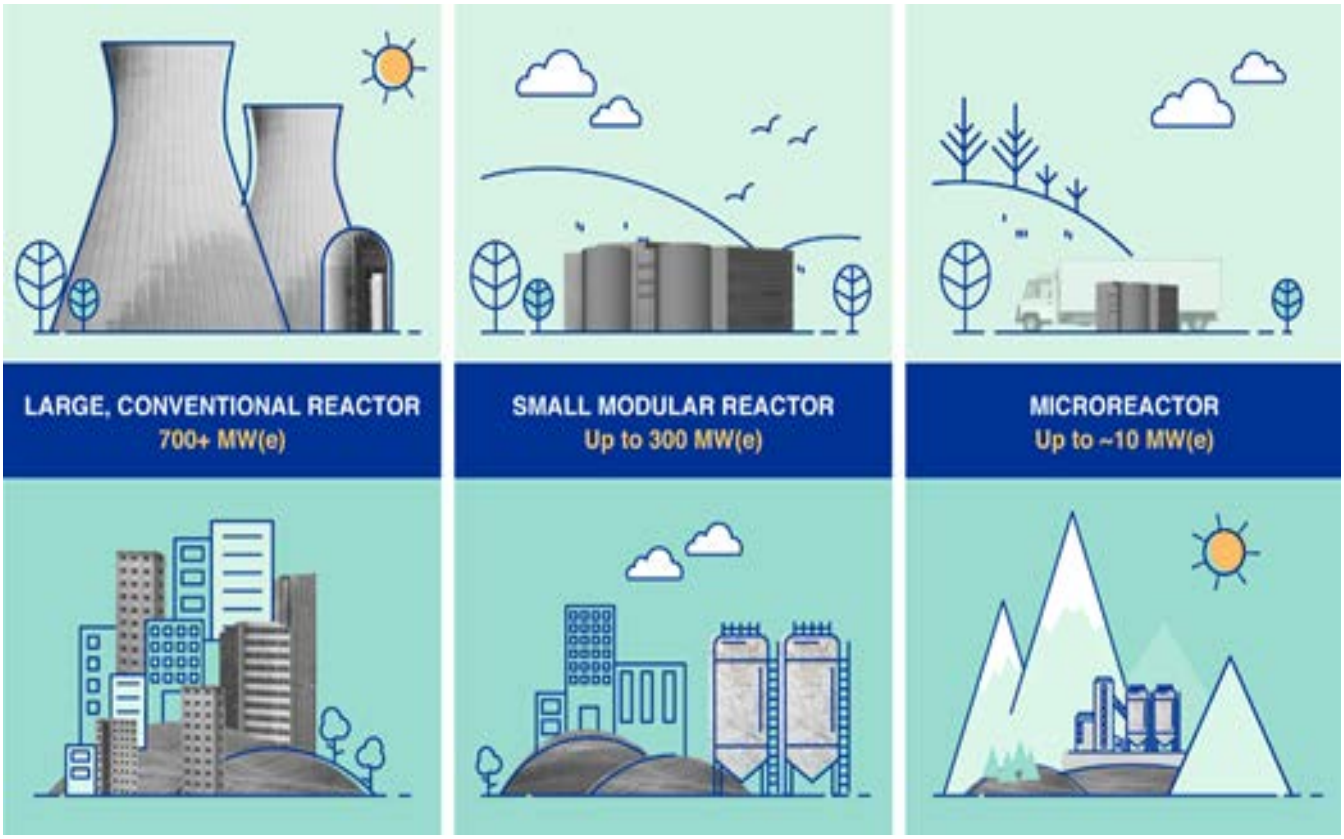


Figure 7. Different reactors.

costs that stymie larger plants. Right now, small modular reactors are a technology of the future, with executives in the nuclear industry generally agreeing that they won't be commercialized in the U.S. until the 2030s. There are currently three operational small modular reactors in the world, according to the Nuclear Energy Agency. Two are in China and Russia, the central geopolitical adversaries of the U.S. A test reactor is also operational in Japan [2,3,4].

9.0 Small Nuclear Power Reactors

Small Modular Reactors (SMRs) are defined as nuclear reactors generally 300 MWe equivalent or less, designed with modular technology using module factory fabrication, pursuing economies of series production and short construction times. This definition, from the World Nuclear Association, is closely based on those from the IAEA and the US Nuclear Energy Institute. Some of the already-operating small reactors mentioned or tabulated below do not fit this definition, but most of those described do fit it. A Pressurized Water Reactor (PWR) is a type of nuclear reactor that uses pressurized water to create heat and produce electricity. PWRs are the most common nuclear power reactors in the world. PWR types may have integral steam generators, in which case the reactor pressure vessel needs to be larger, limiting portability from factory to site. Hence, many larger PWRs, such as the Rolls-Royce UK SMR, have external steam generators (Figure 7).

10.0 Private Investment

SMR development is proceeding with a lot of private investment, including small companies. The involvement of these new investors indicates a profound shift taking place from government-led and -funded nuclear R&D to that led by the private sector and people with strong entrepreneurial goals, often linked to a social purpose (Figure 8)[2-4]. That purpose is often the deployment of affordable clean energy without carbon dioxide emissions. Moreover, small reactors could significantly mitigate the financial risk associated with full-scale plants, potentially allowing small reactors to compete effectively with other energy sources. The Indian government is encouraging private investment in Small Modular Reactors (SMRs) to help decarbonize the country's energy sector: Union Finance Minister Nirmala Sitharaman announced that the government will partner with the private sector to set up SMRs in the budget 24-25. The NITI Aayog has proposed using blended financing and green bonds to attract private investment. Technology companies and energy-intensive industries can be willing partners in this endeavor. Attracting private sector financing for SMRs will be hard without initial support from the government, the report notes, but low-cost finance, green finance and incorporation of nuclear into green taxonomies can improve the economics of SMR projects. De-risking SMR projects and establishing attractive financing frameworks is "pivotal" for incentivising private investors, it says. "It has been observed that venture capital is a poor fit for the 'hard' SMR sector. Hence, the public and private sectors must work together to identify alternative sources of early-stage finance. "India's 22 operable nuclear power plants currently generate only about 3% of the country's electricity needs, but the country has confirmed plans for 21 new reactors (including 8 under construction and one - Kakrapar 3 - which has been grid-connected but is not yet in commercial operation). NITI Aayog has previously said the government should consider SMRs in addition to these plants to help the country reach its energy needs and net-zero goals, and in 2022 Minister of State Jitendra Singh called for the country's private sector companies and start-ups to take part in the development of SMR technology at a workshop held by the think-tank. However, India's 1962 Atomic Energy Act prohibits private control of nuclear power generation and although the act was amended in 2016 to allow Nuclear Power Corporation of India Ltd to form joint venture companies with other Indian public sector units, this does not extend to private sector companies, nor does it allow direct foreign investment in nuclear power, apart from the supply chain.

11.0 Small Modular Reactor Market

- The global small modular reactor market size was around USD 5.84 billion in 2023 and is predicted to grow to around USD 52.02 billion by 2032, with a



Figure 8. Private sector investment is growing in the nuclear sector, an SMR here.

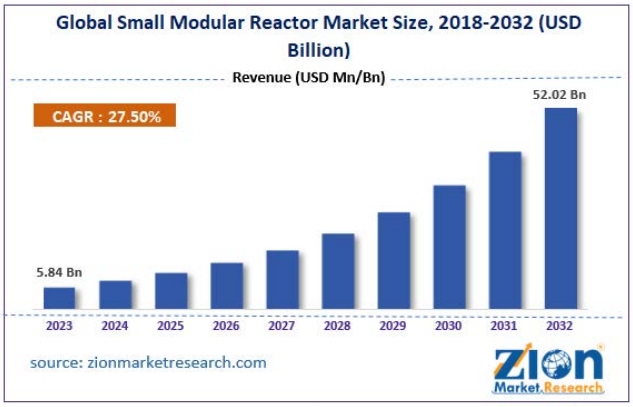


Figure 9. Global small modular reactor market size.

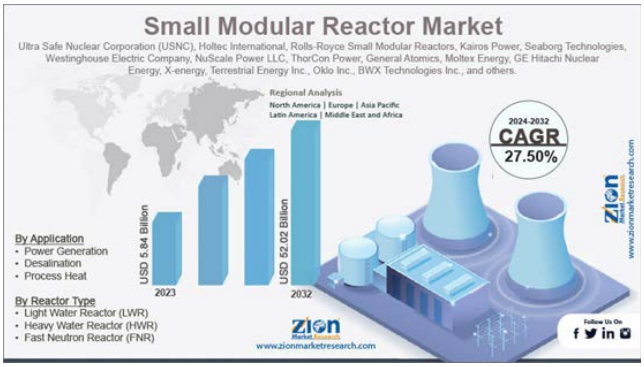


Figure 10. The SMR market is distributed.

Compound Annual Growth Rate (CAGR) of roughly 27.50% between 2024 and 2032. In terms of revenue, the global small modular reactor market was valued at around USD 5.84 billion in 2023 and is projected to reach USD 52.02 billion by 2032. The market is projected to grow at a significant rate due to the rising power demand across the globe. Based on the application, the power generation segment is growing at a high rate and will continue to dominate the global market as per industry projection. Based on the reactor type, the Heavy Water Reactor (HWR) segment is anticipated to command the largest market share. Based on region, Asia-Pacific is projected to dominate the global market during the forecast period (Figures 9, 10).

12.0 Local Market Issues: The Amazon-Susquehanna Event

When Amazon Web Services paid US $650 million in March 2024 for another data center to add to its growing prowess, the tech giant thought it was buying a steady supply of nuclear energy to power it, too. The Susquehanna Steam Electric Station outside of Berick, Pennsylvania, which generates 2.5 gigawatts of nuclear power, sits adjacent to the humming data center and has been directly powering it since the center opened in 2023.

After striking the deal, Amazon wanted to change the terms of its original agreement to buy 180 megawatts of additional power directly from the nuclear plant. Susquehanna agreed to sell it. But third parties weren't happy about that, and their deal has become bogged down in a regulatory battle that will likely set a precedent for data centers, cryptocurrency mining operations, and other computing facilities with voracious appetites for clean electricity[3-5].

13.0 The Controversy

The objection was straightforward. The normal power plants supplying power in the grid and to the public were of the understanding that they would optimise the power charges on a demand and supply equation that would have included the nuclear power also. In case Amazon buys from the nuclear plant, the nuclear power plant has to divert part of the capcity to the Amazon plant."They're effectively going behind the meter and taking that capacity off of the grid that would otherwise serve all customers," says Tony Clark, a senior advisor at the law firm Wilkinson Barker Knauer and a former commissioner at the Federal Energy Regulatory Commission (FERC), who has testified to a U.S. House subcommittee on the subject. The deal between Amazon and the nuclear plant would hurt a third party, namely, all the customers who buy power from AEP or Exelon utilities. The protest

document argues that the arrangement would shift up to $140 million in extra costs onto the people of Pennsylvania, New Jersey, and other states served by PJM, a regional transmission organization that oversees the grid in those areas. "Multiplied by the many similar projects on the drawing board, it is apparent that this unsupported filing has huge financial consequences that should not be imposed on ratepayers without sufficient process to determine and evaluate what is going on," their complaint says.

Susquehanna dismissed the argument, effectively saying that its deal with Amazon is none of AEP and Exelon's business. "It is an unlawful attempt to hijack this limited [ISA] amendment proceeding that they have no stake in and turn it into an ad hoc national referendum on the future of data center load," Susquehanna's statement said. (AEP, Exelon, Talen/Susquehanna, and Amazon all declined to comment for this story.)

More disputes like this will likely follow as more data centers co-locate with clean energy. Kevin Schneider, a power system expert at Pacific Northwest National Laboratory and research professor at Washington State University, says it's only natural that data center operators want the constant, consistent nature of nuclear power. "If you look at the base load nature of nuclear, you basically run it up to a power level and leave it there. It can be well aligned with a server farm." Data center operators are also exploring energy options from solar and wind, but these energy sources would have a difficult time matching the constancy of nuclear, even with grid storage to help even out their supply. So, giant tech firms look to nuclear power to keep their servers running without burning fossil fuels and use that to trumpet their carbon-free achievements, as Amazon did when it bought the data center in Pennsylvania. "Whether you're talking about Google or Apple or Microsoft or any of those companies, they tend to have corporate sustainability goals. Being served by a nuclear unit looks great on their corporate carbon balance sheet," Clark says.

End of Part 1. In the next and concluding part, we will discuss the small modular reactors with uranium and thorium.

The References and Further Reading Section will Come in the 2nd Part.