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Nuclear-powered data centers are on the horizon

Omdia view

Summary

Our need for data centers to power the global digital economy only continues to grow. The challenge is finding a means of powering data centers reliably and sustainably. Demand for renewable energy sources has overwhelmed supply. While data center operators have been early adopters of renewable energy, it is still unavailable in many markets. Demand for electricity is also projected to continuously increase, which will require continuous innovation, optimization, and exploration of new energy sources. This report explores the opportunity to bridge this gap using nuclear energy.

The value of nuclear in small doses

Nuclear is much cleaner than fossil fuels

Renewable energy is generated using sources that are not depleted when used, such as wind, wave, or solar power. Nuclear power is not renewable but has better sustainability credentials than most alternatives. The generation process results in significantly fewer greenhouse gas (GHG) emissions than fossil fuels. Nuclear energy is also cleaner than the hyped wood pellets or biodiesel. One can argue that it is also more reliable and space saving (or energy dense). As a result, nuclear energy is firmly on the discussion table when it comes to figuring out a global strategy to phase out fossil fuels. Some countries have even moved past the discussion phase and have begun implementing nuclear power to considerable effect. For example, approximately 70% of the electricity used in France, a global data center hub, is generated using nuclear power plants and has been, safely, since the 1980s.

Turning nuclear into a small-scale power source

Years of research and funding have made this power-generation technology practical for smaller industrial applications such as data centers. Small modular reactors (SMRs), also known as advanced nuclear reactors and next-generation nuclear reactors, typically generate 300–500 megawatts (MW) of electric power.

Another emerging technology is microreactors, which can produce up to 10MW for smaller applications. It is not a far stretch to imagine these being portable, like a diesel generator or a modular data center.

A deep dive into the history and technology of SMRs is not practical here, so here is a “tip of the iceberg” look at this technology, as conveyed during an in-depth discussion with industry veteran Tony Grayson, currently General Manager of Compass Quantum. While Tony has previously served in data center roles at Oracle, AWS, and Meta, his passion for nuclear power comes from 20 years in the US Navy, three of which he served as Commander of the Los Angeles Class nuclear submarine USS Providence (SSN 719).

Nuclear power usage and safety

Grayson indicated that nuclear power is often misunderstood and perceived as unsafe. This is a primary concern among the general population and is likely to be the argument from “not in my backyard” (NIMBY) activists. Grayson pointed out that nuclear-powered naval vessels have operated since 1955, when the first nuclear submarine, USS Nautilus (SSN 571), first went to sea.

The US Navy currently operates 83 nuclear-powered ships, including 72 submarines, 10 aircraft carriers, and one research vessel, all referred to as nuclear-powered warships (NPWs). Many of these are located adjacent to large population centers. Fortunately, there has never been a nuclear power incident that released any appreciable radiation or radioactive contamination in the US Navy’s history. It should be noted that naval vessel nuclear technology is quite similar to SMRs.

Analysis of catastrophic failures

It is understandable that the broader public perceives nuclear power generation as a significant disaster risk – Chernobyl, Three Mile Island, and Fukushima had a generational impact on large communities. However, it is important to recognize that the primary driver for each of these incidents was human error or a design issue. Additionally, these reactors were much larger and more complex than the future SMRs, which have been re-engineered to make them safer. The US Navy knows this well. Designers and builders of our future SMRs are rapidly learning that simple, low-power, self-contained “walkaway” designs will lead to a safe – and profitable – ability to bring reliable power to remote sites.

Significantly lower radiation exposure

The most significant safety concern associated with nuclear reactors is the potential for a catastrophic release of radiation. SMRs are considerably smaller than the large power plant reactors most of us are familiar with. Thus, SMRs pose far less risk due to their scale, simple design, and the inherent safety characteristics of the reactor, which could utilize low power and low operating pressure, and use passive systems. These systems rely on natural circulation, convection, gravity, and self-pressurization.

Significantly less nuclear waste

Like all nuclear reactors, spent fuel is also a problem with SMRs. The natural decomposition and decay of the spent fuel material to safe levels of radioactivity can take from three decades up to 24,000 years for some fuels. Spent fuel from SMRs will need to be part of any country’s nuclear waste management program. SMR vendors are aiming for refueling cycles every three to seven years (compared to every one to two years for conventional nuclear power plants). Some SMR designs are estimated to operate for 40 years without refueling. Because of the smaller amount of fuel required, and the longer operating life, SMR spent fuel is certainly manageable as part of a comprehensive waste program. Setting such a program up can be a challenge. Two options are:

- On-site storage inside the containment reactor vessel

- Leveraging government sites such as the US Department of Energy's (DOE) Waste Isolation Pilot Plant (WIPP) in New Mexico.

Indeed, some of the SMR and microreactor designs in development utilize fast-fission technology, which can process both spent fuel from future nuclear plants and the spent fuel currently in short-term storage at existing nuclear power plants. For scope, using only the spent fuel in storage at the existing plants, nuclear fast-fission reactors could operate for nearly three centuries without any additional fuel supply.

Nuclear submarine power plants only require refueling every 10 or more years, with new cores designed to last 30–40 years, or even up to 50 years in aircraft carriers, which means that technology is constantly advancing to extend fuel life and recycle spent fuel.

Existing and upcoming SMR designs and use cases

While there are currently no SMRs yet in the US, Russia has commercially operated SMRs, with two 35MW units commissioned in 2020. Notably, with little external inspection and audits, there is limited in-depth data on how these deployments are progressing. However, there are SMRs under construction or in the licensing process in Argentina, Canada, China, France, South Korea, and the US. These will significantly expand the available use case data.

There are over 70 commercial SMR designs globally with varying target markets. In the US, NuScale Power was the first company to be awarded certification from the US Nuclear Regulatory Commission (NRC) in August 2022. This now positions NuScale to sell and install an SMR for a customer. NuScale submitted its original design to the NRC in 2016, so the process has so far been lengthy. Due to the amount of market interest and activity, and government support for SMRs, the NRC is working to scale its support workforce to streamline its processes for the future.

The average one-off 200,000-square-foot data center is not a candidate for dedicated nuclear power SMRs, but a large data center campus would be. A microreactor could also be a good fit. Oklo, a microreactor company from California, is focused on this market specifically. Campuses provide better build economics and are becoming more common. The trend toward larger campuses with capacities of over 100MW would make them ideal candidates for SMRs.

Deployment timeline and economics

We are still in the early innings, but estimates to install and commission an SMR in the US are between five and 10 years. NuScale says the first SMR nuclear power module could be operational within 36 months from actual construction and expects to begin providing modules to its first customer before 2030 and, optimistically, as early as 2027. While we may see a real-world application in the near future, there will need to be some trailblazers to ride out the proof of concept for industrial applications. Data center operators, in general, are not well known as risk takers because they are building for many different customers. Still, cloud and content providers have long-term planning horizons and are likely to be assessing SMR practicality already.

Regulation

One of the more encouraging signs of SMRs' growing adoption is the US government's strong support of this technology. Grayson points out that the NRC thinks of SMRs differently to large nuclear power plants, and overcoming regulatory hurdles is not nearly as challenging. For example, the NRC recently issued a Final Safety Evaluation Report (FSER) regarding NuScale's Emergency Planning Zone (EPZ) methodology. This is critical because the EPZ is now limited to the site boundary, which allows the plant to be sited near cities and end users (like data centers).

As mentioned earlier, one of the biggest obstacles that data center operators must overcome is local dissent for a new data center project. The most practical way to avoid this is the preemptive dissemination of information to a community on how a project's benefits far outweigh the perceived risks. The SMR nuclear story behind Naval vessels is undoubtedly a good existing proof point. For example, residents of Virginia's Tidewater or Washington's Puget Sound region uneventfully co-exist with dozens of SMR-like reactors in their midst. Another good example is the work TerraPower did in Wyoming with town hall meetings before announcing its new site there.

The way forward

In the end, the data center and power-hungry industrial sector's two biggest challenges are the availability of power in constrained markets and feeding power-hungry facilities in a way that minimizes GHG emissions. Power purchase agreements (PPAs) and renewable energy credits (RECs) are nice, but in the long term the industry needs to accelerate the use of sustainable power beyond the current momentum for renewables.

Nuclear power via SMRs is a new alternative to solving these significant challenges without creating more complex-to-sustain demands on the nation's infrastructure. This technology is certainly one to watch. The best way to ensure its success is with a deliberate long-term leadership approach led by the data center community and the SMR designers, working side by side to design and operate custom solutions with this in mind.

Appendix

Further reading

"Eight simple rules about data center sustainability" (November 2022)

"The data center industry's race for sustainability and net zero carbon emissions looks like a sprint" (November 2022)

"The battery market is ramping up – and China is leading the race" (October 2022)

"Schneider Electric advocates for the smart electric grid" (October 2022)

"High power rating UPS open new possibilities for data centers" (October 2022)

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