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Why Small Modular Reactors Are Suitable Underground

By Alvin Chew and Zhou Yingxin

SYNOPSIS

The advent of Small Modular Reactors offers hope for a nuclear renaissance as newcomer countries consider the nuclear option to meet their net-zero carbon emissions target. These reactors if located underground, not only provide superior safety and security protection, but the construction and life-cycle costs could also be more economical than their ground level counterparts.

COMMENTARY

At the turn of the millennium, the global push towards net-zero carbon emissions elevated the nuclear option as a viable source of energy. However, the nuclear accident in Fukushima, Japan, in 2011 dented the confidence of the nuclear industry. This was followed by years of efforts to review the operational safety of existing nuclear power plants.

Large conventional nuclear power plants (NPPs) are unpopular with newcomer states considering the nuclear option. However, the advent of Small Modular Reactors (SMRs) has helped to shape public acceptance of nuclear energy. An SMR has a smaller environmental footprint and is equipped with advanced features that make it safer to operate than larger conventional ones. Global interest in SMRs has also increased because of the possibility of flexible power generation, i.e., the capacity to add more reactors to ramp up output as needed. SMRs also have broader industrial applications, such as desalination or hydrogen production.

Another significant advantage of the SMR is the feasibility of locating it underground.

Maximum Protection Possible

Structures and facilities built underground have the best protection from conventional military attacks. An NPP built underground is fully covered and protected by bedrock, a much stronger geological formation than soil. The safety provided by the rock mass around the reactor is equivalent to that of an aboveground concrete containment structure but with more significant safety margins.

As military weapons become more precise and penetrative, underground rock cavern technology can be used to great advantage. Norway and Sweden have conducted tests showing that 20 metres of competent rock, i.e., rock that can stand for relatively long periods with no support or only minimal support when a tunnel is excavated through it, is sufficient to meet the threat of conventional weapons, offering superior protection compared with aboveground structures or basement-hardened structures using reinforced concrete. The degree of protection will increase with depth.

Besides protection from military threats, underground NPPs offer better protection against natural hazards. Contrary to conventional thinking, the seismic performance of an underground structure is more robust compared to aboveground structures. This is because, during an earthquake, stronger movements are felt at ground level.

Following the Fukushima accident, the International Society for Rock Mechanics and Engineering (ISRM) Commission on Underground Nuclear Power Plant assessed that the disaster could have been avoided if the Fukushima NPP had been built underground based on the concepts presented in the commission's report.

The study also assessed that an underground NPP could have withstood the damaging effects of the tsunami and significantly reduced the contamination effects. It also analysed that had the backup power of the plant been sited underground, it would have been protected from flooding and likely prevented the meltdown of the reactor and subsequent explosion.

Even if a core meltdown is to occur, an underground NPP is designed to have sufficient long and winding tunnels that can serve as "trap zones" for heat from the radioactive decay. The underground tunnels effectively contain and reduce the pressure of the decay heat, minimising the risk of an accidental radioactive release into the atmosphere.

Going Underground Can Be Economical

A common misconception about the nuclear industry is that installing a reactor underground will be less economical because of the high cost of underground construction and the space required for nuclear reactors. However, the concept of an underground NPP envisaged here does not involve the conventional "cut-and-fill" construction method associated with removing ground soil.

Underground NPPs located in rock caverns are created through the "drill and blast tunnelling" method, thereby preserving the structural integrity of the surrounding rocks. With advances in construction technology and engineering design, large rock caverns can now be created very economically at a fraction of the cost of most

underground train stations and tunnels. Around the world, up to 700 hydropower plants are economically sited entirely in rock caverns, offering many lessons for placing NPPs underground.

SMRs will make the construction of nuclear reactors underground more economical as they can be assembled in factories and installed directly underground. Their modular design and smaller size also mean that underground caverns can be designed with optimum size and incremental capacity installation, as the SMR can be easily transported via shafts and tunnels.

Public Acceptance

Another advantage of SMRs is the flexibility of locating them, enabling the reactor to be sited close to city centres. When fully underground, the SMR will offer better protection, zero footprints, free up land and allow aboveground surfaces to be landscaped, which are important considerations in crowded cities. Several technology giants, such as Google and Amazon, have turned to SMRs as a viable solution for powering up their data centres.

While technically feasible to locate underground SMRs in densely populated cities, the NIMBY (Not-In-My-Backyard) syndrome could be an obstruction. It is essential to have public education on the value of nuclear energy and the feasibility of risk management to convince them to accept a nuclear reactor being sited in their midst.

Conclusion

With the Ukraine War showing the Zaporizhzhia NPP's vulnerability to military attacks, the International Atomic Energy Agency (IAEA) could consider setting up technical working groups to study further the feasibility of building underground SMRs. With advancements in rock tunnelling technology, SMRs built underground in competent rock offer a promising option with greatly improved protection and safety at a competitive cost.

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