Small Modular Reactors

SMRs are nuclear fission reactors which are smaller in size than mainstream nuclear reactors. They can be built in one location (generally a factory) and transported to the location where they'll be installed. They typically have an energy output of less than 300 MW (electric) or less than 1000 MW (thermal). Modular reactors are said to improve safety by reducing on-site construction and increasing containment efficiency. Greater safety can be achieved through the use of passive safety mechanisms which operate without the need for human intervention, a concept that is already in use in some conventional nuclear reactor varieties. SMRs also require less staff than conventional nuclear reactors. SMRs are said to overcome financial and safety barriers that prevent conventional reactors from being built.

About Small Modular Reactors

Small modular reactors (SMRs) are high tech nuclear reactors with power capacities of up to 300 MW(e) per unit, or roughly one-third of the power capacity of conventional nuclear power reactors. SMRs, which can generate a large quantity of low-carbon energy, are as follows:

- **Small -** a fraction of the size of a traditional nuclear power reactor.
- **Modular -** making it possible for systems and components to be factory assembled and transported as a unit to a location for installation.
- **Reactors -** use nuclear fission to generate heat, which is then converted into energy.

The term SMR just refers to the size, capabilities, and modular construction of the reactor, not to the type of reactor or the nuclear process used. Designs range from scaled-down versions of current designs to designs of the 4th generation. Thermal-neutron reactors and fast-neutron reactors, as well as molten salt and gas-cooled reactor models, have all been proposed. Staffing, security, and mobilisation time for SMRs vary. One issue with SMRs is the prevention of nuclear proliferation.

Types of Small Modular Reactors

SMRs are envisaged in a variety of configurations. Some are simpler versions of existing reactors, while others are entirely new technologies. Nuclear fission is used in all proposed SMRs, with designs ranging from thermal-neutron reactors to fast-neutron reactors.

Thermal-Neutron Reactors

Thermal-neutron reactors utilise a moderator to slow neutrons and typically use Uranium - 235 (U - 235) as a fissile material. This is the case for the vast majority of conventionally operating reactors.

Fast Reactors

Moderators are not used by fast reactors. They instead depend on the fuel to absorb faster neutrons. Modifying the fuel configuration within the core or using different fuels is usually required. For example, Plutonium - 239 (Pu - 239) is more likely than U - 235 to absorb a high-speed neutron. Breeder reactors can be built into fast reactors. These reactors emit enough neutrons to convert non-fissionable elements to fissile elements. A breeder reactor is commonly used to encircle the core in a "blanket" of U - 238, the most readily available isotope. After undergoing a neutron absorption reaction, U - 238 transforms into Pu - 239, which can be separated from the reactor during refuelling and later used as fuel.

Technologies behind Small Modular Reactors

Cooling the Reactor

Water is used as a coolant in conventional reactors. SMRs can be cooled with water, liquid metal, gas, or molten salt. The coolant type is determined by the reactor type, reactor design, as well as application. Because large-rated reactors principally use light water as their coolant, this cooling method can easily be applied to SMRs. Helium is frequently chosen as a gas coolant for SMRs because it has a high plant thermal efficiency and provides an adequate amount of reactor heat. SMRs commonly use sodium, lead, and lead-bismuth liquid metal as coolants. Sodium was a prominent choice as a liquid metal coolant in early work on large-rated reactors, and it has since carried over to SMRs.

Power Generation

Rather than boiling water, several gas cooled reactor designs propel a gas powered turbine. Thermal energy could be used directly without the need for conversion. Heat energy can be utilised in hydrogen production as well as other commercial operations such as desalination or petroleum product production (extracting oil from tar sands, creating synthetic oil from coal, etc.).

Load Adjustment

SMR designs can either provide constant power or tweak their output based on demand. Another option is to use cogeneration, which maintains consistent output while diverting otherwise unnecessary power to an auxiliary use.

History of Small Modular Reactors

Nuclear reactors have traditionally grown in size due to economies of scale. Nuclear disasters, particularly the 1986 Chornobyl disaster as well as the 2011 Fukushima nuclear disaster, resulted in a significant setback for the nuclear power industry, with worldwide development halted, funding reduced, and reactor plants closed. In response, a fresh approach was devised with the goal of building smaller reactors that are faster to build, safer, and cost less than a single reactor. Despite the loss of scale advantages and significantly lower power output, financing was expected to be easier due to the introduction of modular construction as well as projects with shorter timeframes.

Advantages of Small Modular Reactors

Many of the advantages of SMRs are inextricably linked to their small and modular design. Because of their compact size, SMRs can be installed in areas that would not be appropriate for big nuclear power plants. SMR prefabricated units can be manufactured, transported, and installed on-site, making them less expensive to construct than massive power reactors, which are frequently custom designed for a specific location, causing construction delays. SMRs offer cost and construction time savings, and they can be deployed incrementally to meet rising energy demand.

One of the hurdles to accelerating energy access is infrastructure, specifically constrained grid coverage in remote regions and the expenses of transmission networks for rural electrification. A single power plant should not account for more than 10% of the total installed grid capacity. Because of their smaller electrical output, SMRs can be fitted into an existing grid or remotely off-grid in regions lacking adequate powerlines and grid capacity, offering low-carbon energy for industry and the population. This is especially true for microreactors, a subset of SMRs that can produce electrical power of up to 10 MW (e). Microreactors have smaller footprints than that other SMRs and will be more suitable for regions that lack access to clean, reliable, and affordable energy. Moreover, microreactors could be used as a backup power supply in emergency situations or to replace diesel-fueled power generators, such as those found in rural communities or remote businesses.

Proposed SMR designs are generally simpler than existing reactors, and the safety principles for SMRs frequently depend more on passive systems and inherently safer qualities of the reactor, like low power and operating pressure. Since a passive system depends on physical phenomena like natural circulation, convection, gravitational forces, and self-pressurization, no human interference or external energy or force is needed to shut down systems in such cases. In certain cases, these improved safety margins eliminate or significantly reduce the potential for unsafe radioactive releases to the surroundings and the public in the event of an accident. SMRs have reduced the amount of fuel required. SMR-based power plants might well demand less frequent refuelling, every 3 to 7 years, as opposed to every 1 to 2 years for conventional plants. Some SMRs are designed to run for up to 30 years without needing to be refuelled.

Small Modular Reactors and Sustainable Development

In terms of effectiveness, economics, and flexibility, SMRs and nuclear power plants stand out. While nuclear reactors provide dispatchable energy – they can tweak the output to match power requirements – some renewable energy sources, such as wind and solar, are varying energy sources that change depending on the weather and time of day. SMRs could be combined with renewable energy sources to improve their efficiency in a hybrid power system. These features position SMRs to play an important role in the clean energy transition, as well as in assisting countries in meeting the Sustainable Development Goals (SDGs). Attempts to achieve the objective of universal access to energy, SDG 7, have made visible progress; however, gaps remain, primarily in remote and rural areas. Increased use of renewable energy combined with the emergence of SMRs has the capacity to leverage such gaps as international efforts seek to adopt clean and innovative solutions.

Flexibility of Small Modular Reactors

Because of the flexibility of their modular construction, small nuclear reactors offer many noteworthy technological advancements over conventional nuclear power generation plants. Because of the modularity of an SMR system, additional units can be added incrementally as the load on the grid increases. Furthermore, the modularity of a standardised SMR design allows for rapid production at a lower cost following the completion of the very first reactor on site. Because of SMR's flexibility and modularity, this type of power generation can be deployed at existing power plants, allowing small modular reactors to provide additional energy to the ageing grid of fossil fuel power plants while easily adapting to the existing grid structure. Because SMR plants are modular, "a single location can have three or four Small Modular Reactors, allowing one to go offline for refuelling while the other reactors remain online". SMRs' flexibility opens up new possibilities for industrial applications by saving energy lost during the transition of energy from thermal to electrical. Uses for an SMR under such direct energy transfer circumstances include "desalination, industrial processes, production of hydrogen, oil shale recovery, and district heating", which are not possible with a conventional large reactor.

Nuclear Proliferation

Small modular reactors are concerned about nuclear proliferation, or the use of nuclear materials to make weapons. SMRs are anticipated to be deployed in far more sites than conventional plants due to their lower generation capacity and physical size. Staffing levels are expected to be significantly

reduced as a result of SMRs. The combination raises physical security and safety concerns. Many SMRs are intended to address these issues. Low-enriched uranium with much less than 20% fissionable U-235 can be used as fuel. This small amount of low-grade uranium is less preferable for weapon production. After irradiation, the mix of fission products as well as fissile materials is highly radioactive and needs special management, to prevent casual theft.
In comparison to large conventional reactors, SMRs can be easily adapted to be fitted in a sealed underground chamber, thereby "reducing the reactor's vulnerability to a terror attack or a natural disaster". New SMR designs improve resistance to proliferation. These SMR models provide a solution that can operate the sealed underground for the life of the reactor after installation. Some SMR designs are intended for single-use fueling. Eradicating on-site nuclear fuel handling improves proliferation resistance and allows the fuel to be sealed within the reactor. This design, on the other hand, requires a lot of fuel, which could make it a more appealing target. At the end of its 30-year core life, a 200 MWe light water SMR could contain approximately 2.5 tonnes of plutonium. Furthermore, many SMRs can operate for more than ten years without requiring refuelling, improving proliferation resistance when compared to large conventional reactors, which require refuelling every 18-24 months. Light-water reactors powered by thorium have higher proliferation resistance than the conventional uranium cycle, but molten salt reactors pose a significant risk. Since the reactor is fueled prior to being transported rather than at the final site, SMR factories restrict access.

Waste Production by Small Modular Reactors

Numerous Small Modular Reactors designs is fast reactors with higher fuel burnup, which reduces waste. More fissionable materials can generally be tolerated at higher neutron energies. Breeder reactors do not "burn" U-235, but rather convert fertile materials like U-238 into utilisable fuels. Some reactors are developed to use the thorium fuel cycle, which has lower long-term waste radiotoxicity than the uranium cycle. The travelling wave reactor uses the fuel that it breeds immediately, without the need for the fuel to be removed and cleaned. According to a report by the German Federal Office for the Safety of Nuclear Waste Management, SMRs will still require extensive interim storage and fuel transport. In just about any case, a repository would be needed.

According to one study, some forms of SMR could generate more waste per unit of output as compared to conventional reactors, up to 5 times the spent fuel per kilowatt and up to 35 times other waste products such as active steel. Neutron leakage rates have been estimated to be greater for SMRs because emitted neutrons have lesser opportunities to interact with the fuel in smaller reactor cores. Instead, they leave the core and are absorbed by the shielding, rendering it radioactive. Liquid metal coolant reactor designs become radioactive as well. Another possible problem is that a smaller percentage of the fuel is consumed, which increases waste volumes. The potential for increased reactor diversity may necessitate more diverse waste management systems.

Nuclear Fission

Nuclear fission is the division of a heavy atomic nucleus, like uranium or plutonium, into multiple roughly equal mass fragments. A large amount of energy is released as a result of the process. The nucleus of an atom splits into two lighter nuclei during nuclear fission. In some cases, the process occurs spontaneously, while in others, it is induced by excitation of the nucleus with a wide range of particles (e.g., neutrons, protons, deuterons, or alpha particles) or electromagnetic radiation in the form of gamma rays. A large amount of energy is released during the fission process, radioactive byproducts are generated, and several neutrons are emitted. These neutrons can cause fission in a neighbouring nucleus of fissile material and release more neutrons, resulting in a chain reaction wherein a large number of nuclei fission and a massive amount of energy is released. Such a chain reaction, if controlled in a nuclear reactor, could provide power for societal benefit. If uncontrolled, as it is in the case of an atomic bomb, it can result in a massive destructive explosion.

Nuclear Fusion

Nuclear fusion is the process through which nuclear reactions among light elements result in the formation of heavier elements (up to iron). Significant amounts of energy are released when the interacting nuclei are from elements with low atomic numbers (for example, hydrogen with an atomic number of 1 or its isotopes deuterium and tritium). The vast energy potential of nuclear fusion was first used in thermonuclear weapons, also known as hydrogen bombs, developed in the decade following World War II. In the meantime, the prospective peaceful applications of nuclear fusion, particularly given the virtually unlimited supply of fusion fuel on Earth, have fueled a massive effort to harness this process for power generation.