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Why nuclear power will never supply the world's energy needs

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Nuclear power plant in Dukovany, Czech Republic. Image credit: Petr Adamek.

(PhysOrg.com) -- The 440 commercial nuclear reactors in use worldwide are currently helping to minimize our consumption of fossil fuels, but how much bigger can nuclear power get? In an analysis to be published in a future issue of the *Proceedings of the IEEE*, Derek Abbott, Professor of Electrical and Electronic Engineering at the University of Adelaide in Australia, has concluded that nuclear power cannot be globally scaled to supply the world's energy needs for numerous reasons. The results suggest that we're likely better off investing in other energy solutions that are truly scalable.

As Abbott notes in his study, global power consumption today is about 15 terawatts (TW). Currently, the global nuclear power supply capacity is only 375 gigawatts (GW). In order to examine the large-scale limits of nuclear power, Abbott estimates that to supply 15 TW with nuclear only, we would need about 15,000 nuclear reactors. In his analysis, Abbott explores the consequences of building, operating, and decommissioning 15,000 reactors on the Earth, looking at factors such as the amount of land required, radioactive waste, accident rate, risk of proliferation into weapons, uranium abundance and extraction, and the exotic metals used to build the reactors themselves.

“A nuclear power station is resource-hungry and, apart from the fuel, uses many rare metals in its construction,” Abbott told *PhysOrg.com*. “The dream of a utopia where the world is powered off fission or fusion reactors is simply unattainable. Even a supply of as little as 1 TW stretches resources considerably.”

His findings, some of which are based on the results of previous studies, are summarized below.

Land and location: One nuclear reactor plant requires about 20.5 km^2 (7.9 mi^2) of land to accommodate the nuclear power station itself, its exclusion zone, its enrichment plant, ore processing, and supporting infrastructure. Secondly, nuclear reactors need to be located near a massive body of coolant water, but away from dense population zones and natural disaster zones. Simply finding 15,000 locations on Earth that fulfill these requirements is extremely challenging.

- **Lifetime:** Every nuclear power station needs to be decommissioned after 40-60 years of operation due to neutron embrittlement - cracks that develop on the metal surfaces due to radiation. If nuclear stations need to be replaced every 50 years on average, then with 15,000 nuclear power stations, one station would need to be built and another decommissioned somewhere in the world every day. Currently, it takes 6-12 years to build a nuclear station, and up to 20 years to decommission one, making this rate of replacement unrealistic.

- **Nuclear waste:** Although nuclear technology has been around for 60 years, there is still no universally agreed mode of disposal. It's uncertain whether burying the spent fuel and the spent reactor vessels (which are also highly radioactive) may cause radioactive leakage into groundwater or the environment via geological movement.
- **Accident rate:** To date, there have been 11 nuclear accidents at the level of a full or partial core-melt. These accidents are not the minor accidents that can be avoided with improved safety technology; they are rare events that are not even possible to model in a system as complex as a nuclear station, and arise from unforeseen pathways and unpredictable circumstances (such as the Fukushima accident). Considering that these 11 accidents occurred during a cumulated total of 14,000 reactor-years of nuclear operations, scaling up to 15,000 reactors would mean we would have a major accident somewhere in the world every month.
- **Proliferation:** The more nuclear power stations, the greater the likelihood that materials and expertise for making nuclear weapons may proliferate. Although reactors have proliferation resistance measures, maintaining accountability for 15,000 reactor sites worldwide would be nearly impossible.
- **Uranium abundance:** At the current rate of uranium consumption with conventional reactors, the world supply of viable uranium, which is the most common nuclear fuel, will last for 80 years. Scaling consumption up to 15 TW, the viable uranium supply will last for less than 5 years. (Viable uranium is the uranium that exists in a high enough ore concentration so that extracting the ore is economically justified.)
- **Uranium extraction from seawater:** Uranium is most often mined from the Earth's crust, but it can also be extracted from

seawater, which contains large quantities of uranium (3.3 ppb, or 4.6 trillion kg). Theoretically, that amount would last for 5,700 years using conventional reactors to supply 15 TW of power. (In fast breeder reactors, which extend the use of uranium by a factor of 60, the uranium could last for 300,000 years. However, Abbott argues that these reactors' complexity and cost makes them uncompetitive.) Moreover, as uranium is extracted, the uranium concentration of seawater decreases, so that greater and greater quantities of water are needed to be processed in order to extract the same amount of uranium. Abbott calculates that the volume of seawater that would need to be processed would become economically impractical in much less than 30 years.
- **Exotic metals:** The nuclear containment vessel is made of a variety of exotic rare metals that control and contain the nuclear reaction: hafnium as a neutron absorber, beryllium as a neutron reflector, zirconium for cladding, and niobium to alloy steel and make it last 40-60 years against neutron embrittlement. Extracting these metals raises issues involving cost, sustainability, and environmental impact. In addition, these metals have many competing industrial uses; for example, hafnium is used in microchips and beryllium by the semiconductor industry. If a nuclear reactor is built every day, the global supply of these exotic metals needed to build nuclear containment vessels would quickly run down and create a mineral resource crisis. This is a new argument that Abbott puts on the table, which places resource limits on all future-generation nuclear reactors, whether they are fueled by thorium or uranium.

As Abbott notes, many of these same problems would plague fusion reactors in addition to fission reactors, even though commercial fusion is still likely a long way off.

Of course, not many nuclear advocates are calling for a complete nuclear utopia, in which nuclear power supplies the entire world's energy needs. But many nuclear advocates suggest that we should produce 1 TW of power from nuclear energy, which may be feasible, at least in the short term. However, if one divides Abbott's figures by 15, one still finds that 1 TW is barely feasible. Therefore, Abbott argues that, if this technology cannot be fundamentally scaled further than 1 TW, perhaps the same investment would be better spent on a fully scalable technology.

"Due to the cost, complexity, resource requirements, and tremendous problems that hang over nuclear power, our investment dollars would be more wisely placed elsewhere," Abbott said. "Every dollar that goes into nuclear power is dollar that has been diverted from assisting the rapid uptake of a safe and scalable solution such as solar thermal."

Solar thermal devices harness the Sun's energy to produce heat that creates steam that turns a turbine to generate electricity. Solar thermal technology avoids many of the scalability problems facing nuclear technology. For instance, although a solar thermal farm requires a little more land area than the equivalent nuclear power infrastructure, it can be located in unused desert areas. It also uses safer, more abundant materials. Most importantly, solar thermal can be scaled to produce not just 15 TW, but hundreds of TW if it would ever be required.

However, the biggest problem with solar thermal technology is cloudy days and nighttime. Abbott plans to investigate a number of storage solutions for this intermittency problem, which also plagues other renewable energy solutions such as wind power, in a future study. In the transition period, he suggests that the dual-use of natural gas with solar thermal farms is the pathway to building our future energy infrastructure.

More information: Derek Abbott. “Is nuclear power globally scalable?” *Proceedings of the IEEE*. To be published.