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News Release

Nuclear Power in Singapore? Newly Published Paper Examines the Potential

SINGAPORE - Renewable energy is a concern across the world, but how does a city state the size of Singapore address the growing debate of few natural resources and a rapidly growing population?

'Nuclear Power in Singapore' features in the latest issue of The IES Journal Part A: Civil & Structural Engineering (Volume 3, Number 1, 2010). Written by Andrew Palmer, Seeram Ramakrishna and Hassan Muzaffar Cheema from the Department of Civil Engineering, National University of Singapore, the article examines the possibility and challenges of a nuclear power station in Singapore. Nuclear power in Singapore is certainly a controversial topic, having been debated in the local papers in recent years.

"Singapore has no fossil fuels of its own, and is an unfavourable site for renewable energy. At some point, the possibility of a nuclear power station in Singapore will need to be examined," says Andrew Palmer, the corresponding author. This essay examines the constraints of having a nuclear power station in Singapore and how these constraints might be resolved, in the light of successful nuclear developments elsewhere. It also considers different sites, including underground and offshore. Please see Appendix 1 for the full paper.

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Nuclear Power in Singapore

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Singapore has no fossil fuels of its own, and is an unfavourable site for renewable energy, with the possible exceptions of solar and geothermal energy, the latter on a small scale. It is exposed to supply interruptions and cost increases, and there is likely to be increasing pressure to reduce carbon emissions. Singapore aspires to maintain its position as an influential technological and industrial leader in the region. The possibility of a nuclear power station in Singapore will need to be examined. This essay examines the constraints, among them the small size of Singapore, the heavy demands on land area, and the proximity of neighbouring countries. It discusses how those constraints might be resolved, in the light of successful nuclear developments elsewhere. It then considers different sites, including underground and offshore. A tentative conclusion is that the underground option is the most attractive: that option has been advocated in the past by scientists such as Teller and Sakharov. Security is an important factor in favour of that option.

Keywords: energy, nuclear, security, underground construction

1. Introduction

At some moment – perhaps not yet – the possibility of a nuclear power station in Singapore will need to be examined. Singapore consumes 37.4 TWh (134 PJ) of electricity each year, and spent SG\$8.2 billion on electricity in 2008, double the amount from a decade ago, through energy efficiency has increased (Straits Times, 2009). Singapore has no fossil fuels of its own, and is an unfavourable site for most kinds of renewables. Nuclear power is likely to be a controversial question, and some opinions for and against have already been put forward (Ho, 2007; Straits Times, 2008).

The background is a resurgence of interest in nuclear power and the reduction of fossil fuel consumption (Nuttall, 2005). Worldwide nuclear generating capacity is 370 GW, and nuclear plants generate about 16 per cent of the world's electricity (Lake *et al.*, 2002). The fraction rises to 20 per cent in the USA and 80 per cent in France. China is heavily committed to nuclear energy, in 2008 generated almost 70 TWh, and intends to spend US\$ 50 billion to build 32 nuclear plants by 2020. Political opposition led to many years of delay in the USA and Western Europe, but a comeback is occurring. In Finland, the Olkilouto 3 pressurised-water reactor is under construction and will go into service in 2012, next to Olkiluoto 1 and 2 which have been in operation since 1973.

In this essay, we examine the motivation for thinking about this option, the constraints and difficulties that might arise, what a nuclear power plant might be like, the possible locations, and the research we have currently in progress.

2. Motivation

The motivating factors are energy security, economics, climate change, and industrial and intellectual leadership.

Singapore has no indigenous supply of fossil fuel, and relies entirely on imported gas, oil and in the past coal. That dependence makes it dangerously vulnerable to supply interruptions and to cost increases. It is not a good site for most forms of renewable energy. Wind speeds are too low for wind turbines, the tidal range and tidal currents are too small for tidal energy to make a significant contribution, the sea is too shallow for ocean thermal energy systems, wave energy is minimal (if indeed it makes sense anywhere in the world (Palmer, 2005)), and biofuels require very large areas of land. Solar energy is perhaps an exception, and is the object of an intensive research effort, but Singapore does not have the clear skies of other areas such as the Arabian peninsula, and there is still the issue of energy storage so that electricity can be supplied at night. Geothermal energy is another possibility, but it would be on a small scale (Oliver, 2009).

It is of course arguable that the total exhaustion of fossil fuel supplies lies a long way into the future, and that a rich country will always be able to pay, however high the prices rise. That puts the country at the mercy of gas and oil producers, who are unlikely to be motivated to be generous. Fuel costs make up half the cost of generating electricity in Singapore, and have already increased by 418 per cent since 1999 (Straits Times, 2009).

The scientific consensus (Houghton, 1994; IPCC, 2007) is that a cause of significant climate change is the increase of atmospheric carbon dioxide from 270 ppm in the pre-industrial era to more than 380 ppm now, rising by about 10 ppm per decade and accelerating. A few voices disagree with that consensus. If society is to tackle climate change, many things have to be done, all of them on a huge scale, though some people argue that humankind has more urgent priorities and that this is not the best use of resources (Lomborg, 2006). One obvious course is to dump less carbon dioxide into the air. At Kyoto in 1997, some of the industrialised countries agreed to try to limit their emissions, and a little has been done. The less industrialised countries did not agree to do anything at all. Singapore was not counted at Kyoto among the industrialised ('annex 1') countries. At the Copenhagen 2009 summit Singapore expressed its desire to lower emissions by sixteen percent compared to the business as usual scenario by 2020. Singapore is an industrialised country, and may come under some pressure to conform. Nuclear electricity can also be applied to desalinate water and to make hydrogen from water, and thus makes it possible to shift to non-polluting compressed hydrogen fuel for vehicles, or alternatively to vehicles directly powered by electricity generated from non-fossil sources, and therefore to attain at last a society with zero emissions of carbon dioxide and nitrogen oxides. A complete switch to nuclear power could therefore in principle reduce Singapore's carbon dioxide emissions to a much lower level, leaving only emissions from aircraft and ships, but a less ambitious programme could still make a worthwhile contribution.

Finally, Singapore is a prosperous nation that aspires to maintain its position as a leader in south-east Asia. Part of that role is to be at the technological forefront. Nuclear energy is extending its position, and it might be thought unwise for a country to turn its back. An additional factor is that a nuclear reactor makes it possible to produce other valuable resources, such as Mo-99 for medical applications: in the US about 20 million nuclear medicine procedures are carried out each year.

3. Constraints

Singapore is a small island, some 700 km² in area and significantly extended by land reclamation, roughly in the shape of a squashed diamond 50 km east to west and 25 km north to south, with outer islands to the south and east. Its neighbours Malaysia and Indonesia are close at hand. Malaysia is across the 1 km Johor Strait, and is connected by a causeway and a bridge. The nearest Indonesian island Batam is 20 km to the south.

It is sometimes thought that nuclear power plants have to be in locations far removed from centres of population. That is not correct. While no-one has built a plant in the centre of a city, for several obvious reasons, it is not difficult to find power stations close to cities. In Britain the world's first nuclear power station went into service in 1956 at Calder Hall on the Cumbrian coast, a somewhat remote but not unpopulated area. It was followed soon afterwards by a series of Magnox stations, among them Bradwell, on the Blackwater Estuary 70 km north-east of London, and Berkeley, on the Severn estuary 25 km north of the large city of Bristol.

In Denmark, if you drive from the centre of Copenhagen through the northern suburbs along the Oresund, you soon see across the water the grey bulk of the Barsebäck nuclear power stations in Sweden, some 20 km from downtown Copenhagen and 30 km from Malmö. Barsebäck units 1 and 2 are 600 MW boiling water reactors (BWR) and went into service in 1975 and 1977. They operated successfully, but later became embroiled in the Scandinavian controversy over nuclear power, and eventually unit 1 was shut down in November 1999 and unit 2 in May 2005. Those decisions were on political rather than environmental or technical grounds, and were bitterly contested from across the political spectrum. Svanholm, the chairman of Volvo, said that

“...we will never accept that the country unnecessarily throws away 20 to 30 billion SEK [4 to 6 billion SG\$] while we chop wood to meet energy needs...”

These and other examples are precedents for safe operation of nuclear power, at a distance from a population centre comparable with the distance required in Singapore.

The environmental movement and its allies have a strong political voice. Their opinions change with time, and are much divided. In the 1960s, many environmentalists were in favour of nuclear power. When the Rampart hydroelectric power dam on the Yukon river in Alaska was proposed, conservationists opposed the dam and argued that nuclear power was to be preferred (Brooks, 1965; Coates, 1993). Opinion then shifted, and conservationists came to be generally opposed. Recently there has been a striking shift back, aided by the growing concern about anthropogenic carbon dioxide in the atmosphere, and by the realisation that the agreement at the 1997 Kyoto conference has had almost no effect. Some prominent leaders of the conservation movement have come out in favour. An instance is James Lovelock, the founder and advocate of the Gaia theory, who said in an interview (Lovelock, 2007)

“I'm not a nuclear fanatic. I don't think the right answer is to make the whole world nuclear, that's going too far. I think we have to use the most efficient source of energy that is available, and that will give us what we need while causing the minimum damage to the planet. For densely-populated countries, like Japan, Britain, Germany and many other European countries, nuclear energy is almost ideal. It has a minimal footprint on the Earth, and yet produces huge quantities of electricity at a very reasonable price that will keep cities going. And don't forget: a modern city like London or New York would convert to a camp like one of those in Darfur in one week if electricity were switched right off everywhere.”

It has to be accepted that some conservationists will remain opposed to any application of nuclear energy.

Another potential problem is security. A society is vulnerable to terrorist attack, and a nuclear power plant is an attractive target on which an assault would have a dramatic public impact. Singapore has strong and effective armed forces, civil defence and security institutions. This problem can be solved by a combination of a thoughtful choice of site with efficient surveillance and guards.

A nuclear power plant requires cooling water, which is why many nuclear power stations are built at the side of the sea or a large river. That is not a constraint in Singapore.

Ultimately, a nuclear power station will reach the end of its operating life and need to be decommissioned. There has been concern about radioactive nuclear waste material and where it could be stored. The severity and physical size of the waste problem are often grossly exaggerated. Waste is classified into high-level waste (HLW), defined as waste in which residual radioactivity can induce a significant temperature rise, intermediate-level waste (ILW) and much less radioactive low-level waste (LLW) composed of materials like concrete rubble and protective clothing. The British nuclear power programme has been in service for more than 50 years and constructed 41 power reactors, which at the peak produced one-third of the electricity for a country of 55 million people. In parallel there was an extensive programme of nuclear development for weapons. Taking those two immense programmes together, the volumes of nuclear waste on 1 April 2007 were 1090 m³ of HLW, 236000 m³ of ILW and 3,190,000 m³ of LLW (Williams, 2009). High-level waste is mixed with glass and sealed into stainless steel containers. The 1090 m³ of HLW would fill one standard-size basketball court to just below the baskets.

A nuclear power station in Singapore would not need to create nearly so much waste. Most countries adopt a policy that nuclear waste must be disposed of within their own borders, and the waste question can be managed by underground storage.

Nuclear plants are notorious for delay and cost overruns. Olkiluoto 3 is more than three years late and reportedly 50 per cent over budget.

4. What would a nuclear power station be like?

The earliest nuclear power stations were designed more than 50 years ago. There was no strong reason to minimise the area of the site, and those stations have a reasonably large footprint, as can be seen by looking on Google Earth for Barsebäck in Sweden or Sizewell in England.

A car or an aeroplane designed in 2009 does not look anything like a car or an aeroplane designed in 1959. The same applies to nuclear power stations. A lot of research and development has been carried out, and continued through the cessation of construction that followed the Chernobyl accident. Lake *et al.* (2002) and Nuttall (2005) describe some of the new options. Much research has focussed on the pebble-bed reactor (Thomas 2009), in which the fuel is contained in spheres the size of a tennis ball, each coated with silicon carbide and containing 15000 uranium oxide particles the size of seeds. Helium cools the pebbles and flows to a gas turbine. The helium which leaves the core at 900°C, much hotter than the 300°C of

light-water-cooled conventional designs, and that increases thermal efficiency. The reactor can be much smaller than a conventional nuclear power station. However, the plans for a full-scale pebble-bed reactor in South Africa have been put on hold if not abandoned, though China is reported to be pursuing the concept. The stations now under construction are more conventional in design.

5. Possible locations

A study (Cheema, 2009) looked at the following locations in Singapore:

- 1 the Western Water Catchment Area (around Tengeh, Poyan, Murai and Sarimbun reservoirs, west of Lim Chu Kang road), which covers approximately 50 km²;
- 2 the Central Water Catchment Area (around Bukit Timah);
- 3 Pulau Tekong and other outlying islands;
- 4 Pedra Branca;
- 5 Underground;
- 6 A floating platform out to sea.

The study report includes an assessment of each of these options. Options 1 and 2 were judged less attractive for environmental reasons, impacts on water supply, proximity to residential areas (option 2) and proximity to Malaysia (option 1). Option 3, Pulau Tekong, is quite a large island (24 km²), has no resident population, and is occupied by the military and a reservoir. Pedra Branca is a group of very small islands totalling 8560 m² 45 km east of Singapore, and would require a long power cable: it is too small, and there are possible political issues, since the Middle Rocks only 1.1 km to the south are part of Malaysia.

The floating option 6 has been thought about for many years, and in the 1970s Westinghouse formed an offshore power systems division. More recently, Russia and Japan have taken the lead. Russia is developing small power plants for remote Arctic areas in the north-east, and a 70 MW floating nuclear power station based on a KLT-40C pressurised light-water reactor is currently under construction in St. Petersburg (Green Cross Russia, 2004; Ivanov, 2007; WNN, 2008). The length breadth and draught are 140, 30 and 4.5 m. The target completion date is 2011. The installation location appears still to be uncertain, but the option most often spoken of is Pevek in Chukotka. Slightly to the west, the Sakha autonomous republic is reported to have signed an agreement for four floating reactors. It would be possible to construct such a floating system in Singapore, and to moor it in Singapore waters. It might be thought vulnerable to storms, collisions with ships, aircraft crashes and terrorist attacks. The waters around Singapore are crowded with ship traffic.

The underground option 5 has received strong support from scientists. Sakharov (1921-1989), a distinguished nuclear physicist, Soviet dissident, and Nobel prizewinner, wrote (1989):

“Should nuclear power be developed? If so, should the construction of nuclear power stations – even if they are much more reliable than the one at Chernobyl – be permitted aboveground? Or should they be built underground? These issues are so crucial that they cannot be left to technical experts, and still less to bureaucrats, whose approach is too narrowly technical, too tendentious and sometimes prejudiced, as it is paralysed by a network of mutual solidarity. And the same is true of many other economic, sociological and ecological issues.”

“I personally believe that mankind needs nuclear energy. It must be developed, but with absolute guarantees of safety, which means that the reactors must be built underground. International legislation requiring that reactors be built underground must be prepared without delay.”

Teller (1908-2002) a Hungarian-American theoretical physicist who had been much engaged with the development of the hydrogen bomb, wrote (2001):

“My suggestion...is to place nuclear reactors 300 to 1000 feet [90 to 300 m] underground, in loose earth. In such a location, neither accident nor earthquake could result in a considerable amount of radioactivity's being released on the surface. I think the public misapprehension of risk can be corrected only by such a clear-cut measure as underground siting.’

”The operation of reactors can be greatly simplified by constructing reactors with a negative temperature coefficient. Such a reactor would operate more vigorously when heat was extracted and, conversely, would heat up and shut itself down if little energy was extracted. The natural laws of physics rather than the care exercised by human beings would regulate the operation of such a reactor.”

“In addition, because of its underground containment and the absence of operators, the possibility of obtaining nuclear materials for weapons from the reactor would be sharply reduced. Obtaining nuclear materials from a buried reactor not accessible to human operators would be both expensive and conspicuous.”

In the light of the constraints outlined above, and the overwhelming importance of reassurance to the public about security against terrorism and accident, our tentative conclusion is that the underground option has much to commend it.

6 Further Research

An underground location is more secure, more contained, more difficult to attack, not vulnerable to extreme events like aircraft crashes, does not consume precious surface area, and eliminates visual intrusion. A choice of underground sites involves questions of geology, ground water hydrology, seismic risk and constructibility. A site in granite in the central part of Singapore requires large-scale excavation, and there is evidence that some of the granite is extensively fractured (Oliver, 2005). An excavation in sedimentary rocks such as Pulau Tekong has to be stabilised by retaining walls and protected against ground water inflow. Future studies will examine the underground option in greater detail.

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