Maritime nuclear energy: opportunities and challenges

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Nuclear powered propulsion in commercial vessels has been in contemplation and use since the time that nuclear fission was developed as a power source. In 1959 the first nuclear-powered merchant ship, the NS Savannah, was launched in the US and for a short period until 1970 operated as a demonstration vessel. Other early examples include the Otto Hahn (built in Germany) and the NS Mutsu (built in Japan).

Following these forays, the International Maritime Organization (IMO), an agency of the United Nations responsible for measures to improve the safety and security of international shipping, included a basic regulatory framework in one of its most important conventions, the 1974 International Convention for the Safety of Life at Sea (SOLAS). More detailed requirements were then included in the IMO's 1981 Code of Safety for Nuclear Merchant Ships (the 'Code') but this is now well outdated both in terms of its approach and the technology currently under consideration.

Post-SOLAS there have continued to be developments, most notably by Russia, which currently operates nuclear powered icebreakers – the only current civilian application of marine nuclear power –with further vessels under construction. Last year Russia also started construction of a second power barge designed to operate as a floating nuclear power plant.

However, the development of nuclear-powered merchant ships, leaving aside Russia's ice-breaking vessels, has not progressed since the early demonstration projects. In reality, this was not because of concerns about safety but, and more prosaically, because of costs – fuel oil was a much cheaper resource. While that has not changed, there is now an increasingly strong drive to reduce shipping emissions, particularly given the IMO's goals to cut annual greenhouse gas emissions.

Furthermore, recent global events – in particular Russia's invasion of Ukraine – have also brought into focus the risks of over-reliance on fossil fuels. Marine nuclear power is, therefore, back in focus, alongside other low emission fuel options such as hydrogen, methanol, ammonia and battery power.

Limited progress has been made in nuclear propulsion in a commercial setting, but it has been widely used in naval vessels since the mid-1950s. Indeed, over the last 70 years, several hundred nuclear reactors have been deployed in a marine environment whether onboard submarines or naval ships. When one considers that there is also significant experience in the operation of onshore nuclear reactors, it is clear that there is a large body of collective experience available to call upon. In many ways, therefore, the building blocks for nuclear powered vessels are there, but the stakeholders involved face a number of challenges.

LONG-DISTANCE SHIPPING

In the early part of the last decade, the IMO adopted the first set of international (mandatory) measures to improve ships' energy efficiency. Since then, further steps have been taken and, in 2018, the IMO adopted a formal strategy, setting targets for reductions in the carbon intensity of international shipping and total annual greenhouse gas emissions. In particular, the goal is for greenhouse gas emissions from international shipping to be reduced by at least 50% by 2050 compared to 2008.

This is, however, a challenging target when one considers that over approximately the next two to three decades, estimated population and GDP growth will hugely increase demand for ships to carry cargo around the world. As such, current tonnage, the overwhelming majority of which is powered by fuel oil, will need to be made 'greener' and new tonnage will need to be constructed with these goals in mind.

There are different ways to achieve this, including improving efficiencies in propulsion systems, hull design and vessel operation, but the most significant is the fuel source. The difficulty for the industry, however, is that there is not as yet any clear direction

on which of the alternative fuel sources will dominate – and it is likely that the type of fuel source will differ depending on whether it is used on smaller ships making shorter voyages or larger deep-sea trading ships.

It is in the context of deep-sea trading ships such as large bulkers, container vessels and tankers that nuclear propulsion has, at least for the time being, the most potential, given the very substantial volumes of fuel that these vessels require. An example given by one analyst recently is that a large container ship constructed to run on methanol would need approximately 400 tonnes of methanol per day, requiring 36 offshore wind turbines to produce it as a green fuel. While there are alternative ways to produce the fuel needed, the point is that producing sufficient quantities from green electricity for the many ships required will be a challenge.

This is where the use of nuclear reactors has a very significant upside, because nuclear fission can generate the same amount of energy as burning fossil fuels, with around one millionth of the volume of fuel material. The disparity increases even more with green fuels such as methanol and ammonia. Nuclear fission also does not have greenhouse gas emission, so would hugely assist in achieving the IMO's goals, given that large deep-sea vessels contribute most of the emissions.

The technology under consideration is based on Small Modular Reactors (SMRs) that are not pressurised; this is distinct from the Pressurised Water Reactors (PWRs) that have been historically used in some of the large onshore reactors. Examples of the type of technology being proposed include molten salt reactors and micro heat pipe reactors. The use of modular reactors has an important upside in that it should be possible to install them into vessels with relative ease, and because they are not pressurised, they pose much less of a risk than PWRs and, arguably, also less of a risk than other low carbon alternatives such as hydrogen and ammonia, where the process of bunkering (refuelling) is likely to be particularly challenging.

This technology is being progressed rapidly, and it now seems that it is not a question of if there will be nuclear powered commercial vessels, but when – with current estimates suggesting that the first vessels fitted out with SMRs will be completed within this decade.

HOW TO REGULATE

As indicated, there is a semblance of regulatory controls in place for nuclear power in a marine application, in particular the IMO's 1981 Code. However, the Code is based on PWR technology and it also applies a very prescriptive approach not in line with the more outcome-orientated practice used generally in the nuclear sector – see, for example, the International Atomic Energy Agency's Safety Standards. One of the biggest challenges is therefore establishing a modern multi-lateral regulatory framework. This will, however, take time and it might be well in to the 2030s before the IMO has an updated Code, by which time it is already intended that nuclear powered ships will be in operation.

Initial progress in this area is likely to take place at a bi-lateral level, with like-minded states implementing a regulatory framework that will allow nuclear powered vessels to operate. This might, for example, see cooperation between nations such as the US, UK, France and Japan. Each has significant collective nuclear experience and would likely be willing to agree suitable parameters that would permit nuclear powered vessels to operate between designated ports within their jurisdiction. If this was a success, that would in turn provide the blueprint for a multi-lateral approach by the IMO in due course. In this respect, the UK is already looking ahead to such an approach and, as a starting point, has now enacted legislation to implement the Code – the Merchant Shipping (Nuclear Ships) Regulations 2022.

The regulatory bodies tasked with classifying vessels according to certain

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standards are also taking steps. The American Bureau of Shipping (ABS) has a contract from the US government to research the barriers to progress such that new reactor technology can be rapidly deployed for commercial applications. Certainly, in the view of the US Department of Energy, nuclear power is seen as one of the strongest tools available to help the shipping industry achieve its emissions goals. Similarly, LR (Lloyd's Register) is also taking steps to support the stakeholders looking to deploy nuclear powered vessels within this decade by developing a new set of rules for nuclear powered vessels (it did produce a set of rules in the 1960s, but these were since withdrawn) and it will publish high level requirements in 2023. Both ABS and LR are widely used classification societies for newbuilding projects all over the world and their involvement is critical.

PUBLIC PERCEPTION

One of the greatest potential obstacles facing the widespread adoption of nuclear-powered vessels is public opposition, largely founded on the misunderstandings – often engendered and promoted by media – that surround the dangers posed by nuclear fuels, particularly in comparison with the dangers posed by alternative fuels.

One of the main public concerns around nuclear fuel is the perceived security risk it would generate. To a lay person, putting a nuclear reactor on a vessel will sound like putting a nuclear bomb on a mobile platform to which a terrorist would need to 'just add explosives' in order to wreak chaos on a wide area. However, while this could potentially have been an issue with PWRs, the reactors currently intended for maritime use generally operate at ambient pressures and in passively safe ways where leaks act as an arresting factor on reactivity.

In this respect, one of the key regulatory issues for stakeholders is the Emergency Planning Zone (EPZ) – an area within which detailed plans are required in case of emergency. For land based nuclear reactors, EPZs cover a considerable area. However, that would present a significant problem in the context of a nuclear-powered ship moving between ports. It is therefore precisely because of the features of these non-pressurised reactors that stakeholders have suggested that the EPZ should be much smaller and limited to, potentially, the confines of the ship.

In addition to these passive safeguards, the maritime industry is also well accustomed to ensuring that fissile materials are suitably protected during transit and the same principles can easily be applied to reactors placed on board vessels. For example, a substantial collision in 1954 between a car ferry and the cargo ship Mont Louis, which was carrying uranium hexafluoride, resulted in no detectable radioactive discharge. Since then, safety mechanisms have, of course, been further improved.

A challenge for the wider industry to overcome will also be the processing of the nuclear waste. This is lessened by the relatively small volume of material used in the first place and the fact that the reactors under consideration, such as molten salt reactors, consume much of the initial bi-products of fission. Additionally, and unlike the bi-products of burning fossil fuels, the remnants can be recycled into other productive roles, for example in medical radiology or by being re-processed for further reaction. However, there will be radioactive waste that cannot be recycled and this will need to be safely and securely stored. That will come at a cost, but the present view of the stakeholders involved is that the amounts will not, in relative terms, be significant and this is a process that can be effectively managed.

THE ROUTE AHEAD

Use of nuclear reactors is not a silver bullet in the push to reduce carbon emissions from shipping. It does, though, plainly have the potential to make a very big difference if utilised alongside the other low carbon alternatives. There are of course various barriers to progress, including the implementation of a multi-lateral regulatory framework and safely and securely dealing with waste material. Additionally, careful thought will need to be given to the contractual arrangements governing the construction of nuclear-powered vessels, their subsequent maintenance arrangements and the ownership of the reactor itself.

Perhaps, though, the greatest challenge is that, at least in the early stages, the costs of manufacturing the nuclear reactors are likely to be considerably greater than alternative propulsion systems. However, if use of nuclear reactors becomes more widespread and there is a degree of uniformity in the designs then these costs will reduce. It is also relevant that the reactors will not need to be refuelled. Indeed, in the case of molten salt reactors, which would be intended for use in large deep-sea ships, it is estimated that the reactors can operate for up to 30 years without refuelling. Leaving aside reactor maintenance costs, that will represent a considerable saving in the cost of operating the vessel.