



Unlocking Tritium for Fusion Energy

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Unlocking Tritium for Fusion Energy

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SYNOPSIS

Tritium has been identified as an integral fuel element for the fusion process. However, given its scarcity and short half-life, it is crucial to optimise tritium production to enable the commercialisation of future fusion reactors.

COMMENTARY

The research and development in fusion energy have accelerated in recent years. Touted as “30 years away - and always will be,” the “holy grail” of power has, in the past few years, achieved significant developmental milestones. In 2021, researchers at the Massachusetts Institute of Technology (MIT) built high-temperature superconducting magnets that could be deployed in future commercial fusion reactors. In 2025, France set a record for sustaining a fusion plasma in a tokamak for 22 minutes. In terms of net energy gain, the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL) in California, United States, managed to yield more than twice the energy input when it experimented with the inertial confinement method.

Despite these breakthroughs, Pietro Barabaschi, Director-General of the International Thermonuclear Experimental Reactor (ITER) project, commented that fusion is still a [long way](#) from full commercialisation. The ITER project, initially scheduled to start in 2025, has been pushed back to 2035. From that point, the experimental reactor will still need another twenty years of testing to serve as a blueprint for future commercial reactors to be connected to the grid. This means that fusion energy will most likely be available after 2055, which is still 30 years away. But the timeline is more definite now.

Despite the lengthy timeline, investors have been pouring massive funds into fusion research. The global fusion industry has attracted more than 50 start-ups, all

pursuing parallel tracks of development to commercialise fusion energy by the next decade. However, the industry will face a problem in fuelling its reactors – the availability of tritium.

Dwindling Global Stockpiles of Tritium

The deuterium-tritium combination has been identified as the most efficient fuel for fusion. Deuterium is abundant in seawater and can be extracted easily. Tritium, on the other hand, is scarce in nature and forms only when gases in the upper atmosphere interact with cosmic rays. Hence, the global inventory of tritium is a by-product of nuclear fission in Canada Deuterium-Uranium (CANDU) heavy-water reactors.

There are currently 17 CANDU reactors operating in Canada, which, in total, can produce up to 2 kg of tritium annually and sell it to the world at US\$30,000 per gram. Their capacity to produce tritium will decline over time as several ageing CANDU reactors will be replaced by smaller light-water reactors. The Republic of Korea (ROK) and Romania also operate heavy-water reactors, which can add to the global tritium stockpile.

The current global stockpile of tritium is about 20 kg. The ITER project is expected to consume about 12 kg of tritium throughout its operational lifespan. Assuming Canada, ROK and Romania continue to produce tritium at a moderate rate, it is estimated that by 2055 (after ITER has ceased operation), the global tritium stockpile could dwindle to 14 kg, which would be insufficient for any fusion reactor to begin operating then. Studies estimate that a 1 GW fusion reactor will require about 55 kg of tritium annually.

A commercial fusion reactor is designed to breed tritium, but this will only occur when the reactor is running in a steady-state condition, in which sufficient neutrons bombarding with lithium inside the reactor can produce tritium to sustain the operation. Therefore, breeding tritium in a fusion reactor remains hypothetical. The reactor will still require a considerable amount of tritium to ignite the fusion process.

Tritium and Nuclear Weapons

Tritium has also been produced with conventional light-water reactors in the US. The Tennessee Valley Authority (TVA) Watts Bar plant produces tritium by coating control rods with boron to capture neutrons. However, tritium production is tightly regulated by the National Nuclear Security Administration (NNSA) in the US because the stockpile is used primarily to boost the yield of its nuclear weapons.

In 2000, TVA entered into an agreement with NNSA to provide tritium production services from its reactors until 2035. While tritium stockpiling is small in the US due to its limited use in nuclear weapons, the US should consider scaling up its proven supply chain of tritium and play a leadership role in the future deployment of fusion reactors.

Tritium Production from Nuclear Waste

Spent nuclear fuel can be reprocessed for use as fuel in fission reactors. However, the reprocessing of spent fuel raises international concerns about proliferation, and it has also been proven uneconomical. Therefore, spent fuel is disposed of as nuclear waste and temporarily stored in on-site metal casks. Nevertheless, nuclear wastes still pose a significant issue, as improper management can lead to environmental contamination.

Researchers at the Los Alamos National Laboratory (LANL) in the US are investigating the use of particle accelerators to produce tritium from nuclear waste. Computer simulations are performed to study the feasibility of firing proton beams onto spent fuel rods coated with molten lithium salt, which would initiate a fission process that converts lithium into tritium. In short, it is reigniting the fission process on the waste using an accelerator rather than in a reactor pressure vessel.

The production of tritium via this method has three benefits: i) The use of accelerators provides a more controlled environment for the fission process; ii) Operational output of the nuclear plant will not be compromised, as it is performed on wastes that have been taken out of the reactors; iii) There will be less waste to manage.

If viable, nuclear waste could become a gem, triggering a sea change in policies for radioactive waste management. Upcycling nuclear waste into tritium for use in fusion reactors is turning a problem into an opportunity. While it will ease the management of nuclear waste, it will also increase the supply of tritium, lowering the potential commercial cost of fusion energy.

Conclusion

Production of tritium will still be tightly regulated internationally due to its potential use in nuclear weapons. Therefore, not every country will have access to the technology and tritium production supply chain. Countries with the capability to manufacture tritium, such as Canada, South Korea, and Romania, which operate heavy-water reactors, should consider ramping up their tritium production to prepare for the large-scale deployment of fusion energy globally. Furthermore, if the extraction of tritium from nuclear waste proves viable, it will certainly offer more options for waste management.

Unlike rare earth materials, which are mined, tritium must be produced by nuclear fission. Despite the current geopolitical climate, it is unlikely that rivalry will surface in the tritium economy, as the major players researching on fusion are contributing to the development of the ITER project. There will be no problems for ITER operations, as Canada has agreed to supply tritium. The problem of tritium supply only arises after the commercialisation of fusion.

Timing is critical. As the half-life of tritium is about 12 years, there is no need to rush into tritium production if fusion energy will be commercialised in 30 years. However, policymakers need to start thinking of strategies to shore up the fission fuel cycle for tritium production, such as extending the operation of heavy-water reactors or taking

back spent fuel and nuclear waste for upcycling. The world needs the nuclear fission industry to realise fusion energy in the future.

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