As part of the RCUK-India civil nuclear research collaboration, British and Indian researchers have sought to determine the advantages, disadvantages, and viability of open cycle thorium–uranium-fuelled (Th–U-fuelled) nuclear energy systems. The researchers have taken a strong definition of “open” nuclear fuel cycle, assuming that no separated fissile materials (such as separated plutonium) are available from previous reprocessing. As such, the reactors systems are initiated and operated using enriched uranium. Three Th–U-fuelled reactor systems using uranium enriched to ∼20% $^{235}$U have been assessed. These were: AREVA’s European Pressurised Reactor (EPR); India’s Advanced Heavy Water Reactor (AHWR); and General Atomics’ Gas-Turbine Modular Helium Reactor (GT-MHR). These technologies are compared to a reference uranium-fuelled EPR.

The work presented relates to two separate journal articles [1,2]. The first study focussed on assessing various performance indicators, spanning material flows, waste composition, economics, and proliferation resistance [1]. The values of these indicators were determined using the UK National Nuclear Laboratory’s fuel cycle modelling code ORION [3]. This code required the results of various nuclear reactor physics codes and burn-up routines to model the neutronics of each nuclear energy system. In summary, all three Th–U-fuelled nuclear energy systems required more separative work capacity than the equivalent benchmark U-fuelled system, with larger levelised fuel cycle costs and larger levelised cost of electricity. Although a reduction of ∼6% in the required uranium ore per kWh was seen for the Th–U-fuelled AHWR compared to the reference U-fuelled EPR, the other two Th–U-fuelled systems required more uranium ore per kWh than the reference U-fuelled EPR. Negligible advantages and disadvantages were observed for the amount and the properties of the spent nuclear fuel (SNF) generated by the various systems considered. Two of the Th–U-fuelled systems showed some benefit in terms of proliferation resistance of the SNF generated. Overall, it appears that there is little merit in incorporating thorium into nuclear energy systems operating with open nuclear fuel cycles.

The second sought to investigate how life-cycle emissions would be affected by including thorium in the nuclear fuel cycle, and in particular its inclusion in technologies that could prospectively operate open Th–U-based nuclear fuel cycles [2]. The same three potential Th–U based systems operating with open nuclear fuel cycles were considered as in the first study A life-cycle analysis has been performed that considered the construction, operation, and decommissioning of each of the reactor technologies and all of the other associated facilities in the open nuclear fuel cycle. This included the development of life-cycle analysis models to describe the extraction of thorium from monazitic beach sands and for the production of heavy water.

The results of the life-cycle impact analysis highlight that the reference U-fuelled EPR has the lowest overall emissions per kWh generated, predominantly due to
having the second-lowest uranium ore requirement per kWh generated. The results highlight that the requirement for mined or recovered uranium (and thorium) ore is the greatest overall contributor to emissions, with the possible exception of nuclear energy systems that require heavy water. In terms of like-for-like comparison of mining and recovery techniques, thorium from monazitic beach sands has lower overall emissions than uranium that is either conventionally mined or recovered from in-situ leaching. Although monazitic beach sands (and equivalent placer deposits) only form 30% of the overall known thorium ore deposits, it is expected that such deposits would generally be utilised first, if thorium becomes a viable nuclear fuel. Overall, for these four nuclear energy technologies, the range of CO$_2$(eq) emissions per kWh generated (6.60–13.2 gCO$_2$(eq)/kWh) appears to be low in comparison to the majority of electricity-generating technologies.

The two studies indicate that thorium fuel offers little or no benefit over conventional uranium fuelled approaches for open-cycle nuclear energy production. We suggest that short- to medium-term interest in thorium should be restricted to those countries with an interest in nuclear fuel reprocessing or with a need to reduce inventories of fissile material (such as separated plutonium).

Acknowledgements

The work was funded by the Engineering and Physical Sciences Research Council under grant no. EP/I018425/1. We are most grateful to all those who worked to establish the RCUK-India civil nuclear collaboration. The research has been undertaken by a range of researchers, including most notably Dr Stephen F. Ashley whose efforts lie at the heart of the work reported.

References

References

