Written Evidence Submitted by Dr. Guy Matthews FInstP

Having listened to the recording of the Parliamentary Science and Technology Committee's meeting on nuclear fusion held on 25th May 2022, my purpose in this document is to suggest areas where more challenging questions might be asked. More specifically, I give my view of the risks associated with the UK's current strategy for fusion and its inability to tackle the challenge of net zero either nationally or globally. My submission is based on 40 years' experience in fusion physics and technology. In particular, I was leader of a project that changed the JET wall from carbon to its current ITER-relevant beryllium and tungsten material. I was a JET scientific task force leader for 12 years and currently chair an expert group advising JET on preventing plasma damage to wall components. I am writing in a personal capacity.

1. Physics and Technology Risks

Many physicists believe that the impression that fusion is on the verge of a technological/commercial end game is false because the uncertainties in the physics are understated or ignored. In particular, the extrapolation from existing machines to the UK's Spherical Tokamak for Energy Production (STEP) is so great that there is an extreme risk of failure due to uncertainties. This risk might be reduced given a longer timescale and results from the operation of ITER and spherical tokamaks of intermediate size. As an example, the energy stored in the STEP plasma needs to be about 5,000 times larger than that which has been produced so far in the UK's MAST-U spherical tokamak experiment. Since physics models often struggle to explain or predict differences between machines of similar size, this is a brave extrapolation. STEP's selling point is that it packs much more fusion power, and hence plasma energy, into a smaller machine than conventional tokamaks. STEP is comparable in size to JET but needs to have about 50 times the total plasma energy. This is a matter of serious concern because no sufficiently robust or predictable way has yet been found to avoid fast losses of hot plasma onto the walls due to instabilities in the plasma. Some of these phenomena behave in a similar way to solar flares, while others force the entire plasma onto the wall. Considerable damage can be expected unless such hazards can be eliminated. Even if we could reliably avoid or mitigate these instabilities in MAST-U, the extrapolation to STEP is so great that it only adds to a long list of similar risks.

2. The Role of ITER in UK Strategy

In ITER's current Research Plan,[1] the first meaningful results in terms of fusion power are scheduled to come in 2036, with the Plan ending in 2041. ITER needs the plasma self-heating that comes from the deuterium-tritium (D-T) fusion reactions to reach high performance. This is the phase in which its most important results will be produced. The UK contributed to the writing of the current European Research Roadmap to the Realisation of Fusion Energy.[2]This document envisages that ITER results will provide "essential contributions" in physics and technology to the detailed design of its first electricity generating reactor (DEMO). The UK's strategy to construct its STEP power plant by 2040 means that all the design decisions will already have been taken without benefit from the data yielded by the full-power operation of ITER. Without these data, much larger extrapolations have to be made in the physics and unproven technologies selected. The UK strategy to leapfrog ITER appears extremely risky. Otherwise put, the STEP project runs a major risk of failure without a change of approach.

3. Implications of Fast-Track Fusion for Materials and Radioactive Waste

Fusion reactions between deuterium and tritium are by far the easiest to achieve and, for now, are the only credible basis for a reactor. However, 80% of the power is delivered as fast neutrons, which must be used to generate the tritium fuel in a massive breeding blanket which may require periodic replacement.

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[1] https://www.iter.org/doc/www/content/com/Lists/ITER%20Technical%20Reports/Attachments/9/ITER-Research-Plan_final_ITR_FINAL-Cover_High-Res.pdf

[2] https://www.euro-fusion.org/eurofusion/roadmap/

Unwanted nuclear reactions occur between these neutrons and primary elements or impurities in the blanket or reactor structure, creating radioactivity and degrading the materials. If conventional engineering materials are used, fusion reactors have the potential to generate far larger volumes of long-lived radioactive waste than fission reactors. Given public sensitivity to the issue of nuclear waste, this is an important point to explore in any discussion of strategy and of the implications for the UK's waste storage capacity. The materials needed for a genuinely sustainable and commercial fusion reactor do not yet exist and may take decades to develop, qualify for nuclear use and industrialise. First of kind materials will also make commercial fusion reactor prototypes very expensive to construct.

4. Fusion Power, Net Zero and Climate Change

The panel of experts at the 25th May meeting were unanimous that fusion could not make any useful contribution to the UK's goal to achieve net zero by 2050. It was suggested that the role of the UK's fusion programme was to help the rest of the world achieve net zero; however, this seems questionable. If we take the goal of 2040 for the construction of STEP at face value, and we assume it works perfectly, then net electricity output will be demonstrated sometime in the 2040s. Prof. Garwood explained why at least two more decades will then be required before the first fully integrated, commercially viable plant is produced. Even with a fusion reactor roll-out in the 2070s, constructing the thousands of reactors needed to be globally significant, and supplying them with enough tritium to start operating, will take well into the 21st century. Fusion, therefore, is manifestly not the right technology to help the world achieve net zero, since it arrives too late at the necessary scale. The European Research Roadmap reaches the same conclusion. It envisages fusion replacing fission and carbon capture and storage plants during the course of the next century, not helping to achieve net zero by 2050. The ambitious acceleration of this timescale by the UK will not change this conclusion.

5. Private Fusion Companies

The current high levels of private investment in fusion start-ups is a sign of effective marketing, rather than an indication that the complex physics problems or tricky nuclear technology will be quickly swept away by creative thinking. The following YouTube video (not by me) provides an accessible explanation of the need for scepticism and why we will not have fusion power by 2040: https://www.youtube.com/watch?v=JurplDfPi3U. Prof. Garwood's comments about the decades required to move from first demonstration to commercial plants are also relevant to private-sector fusion devices.

Conclusion

The challenge for politicians or investors when making decisions about fusion is its complexity. Fusion R&D is making progress, but there is little incentive for those seeking funding to be open and transparent about the extent of the remaining gaps in the physics and technology, or the uncertainties around the ambitious extrapolations being made from current experiments. Another "inconvenient truth" is that, while fusion energy is usually presented as clean, sustainable and cheap, it is unlikely to be any of these things without many iterations of fusion technology at the reactor scale. New materials will also be needed which do not yet exist and could prove elusive to create.

It is appealing to believe that the UK will build a fusion power plant ahead of the rest of the world in a single giant leap, but this seems highly unrealistic. All the members of the expert panel agreed that fusion will not help the UK reach net zero. If the UK's strategy is to help the rest of the world achieve this goal, then fusion will arrive too late to stop catastrophic climate change, even on the most optimistic assumptions. To end on a more positive note, the UK's ongoing engagement with the international fusion programme will retain many of the benefits in terms of skills and spin-off that come from long-term R&D in a field with many diverse challenges but which may one day provide a valuable energy source.