4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Challenges and progress on the path towards fusion energy

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The European Roadmap to the Realisation of Fusion Energy[1] breaks the quest for fusion energy into eight missions. For each mission, it identifies open issues, and proposes a research and development programme. It points out the needs to intensify industrial involvement, to educate the fusion scientists and engineers of the future, and to seek all opportunities for collaboration outside Europe. The eight missions are:

1. Plasma regimes of operation: Demonstrate plasma scenarios (based on the tokamak configuration) that increase the success margin of ITER and satisfy the requirements of DEMO.
2. Heat-exhaust systems: Demonstrate an integrated approach that can handle the large power leaving ITER and DEMO plasmas.
3. Neutron tolerant materials: Develop materials that withstand the large 14MeV neutron flux for long periods while retaining adequate physical properties.
4. Tritium self-sufficiency: Find an effective technological solution for the breeding blanket which also drives the generators.
5. Implementation of the intrinsic safety features of fusion: Ensure safety is integral to the design of DEMO using the experience gained with ITER.
6. Integrated DEMO design and system development: Bring together the plasma and all the systems coherently, resolving issues by targeted R&D activities
7. Competitive cost of electricity: Ensure the economic potential of fusion by minimising the DEMO capital and lifetime costs and developing long-term technologies to further reduce power plant costs.
8. Stellarator: Bring the stellarator line to maturity to determine the feasibility of a stellarator power plant.

Now we are approaching the end of the 8th European Framework Programme (2014-2020), it is a good moment to look back at the achievements since the establishment of EUROfusion in 2014, while at the same time have a peek into the future, to see which challenges lay ahead of us as well as the strategy to tackle them.

EUROfusion has seized the unique opportunity to develop an integrated scientific programme including experiments and modelling on devices with different sizes, i.e., on medium-size tokamaks and on JET to provide a step-ladder approach for extrapolations to JT-60SA, ITER and DEMO. Strong synergy in the programme of the various European devices has been central and has focused on optimising ITER's performance from day one of its exploitation.

The main development in plasma scenarios (mission 1) has been the move to tokamak operation with metallic walls like ITER and DEMO (previously carbon was the normal plasma-facing material, which proved unsuitable for ITER and DEMO). This has led, as hoped, to strongly reduced tritium retention and much lower levels of dust production. The introduction of metallic walls initially had an adverse effect on the plasma performance for standard plasma scenarios but various remedies and modified scenarios have been developed to assist rapid progress when ITER starts to operate.

In the challenging area of plasma exhaust (mission 2), there has been good progress in understanding the likely exhaust loads in ITER and DEMO. As a response, a comprehensive high-level strategy has been developed and a range of facility enhancements funded in support. Furthermore, the Italian government has recently decided to proceed with the funding for the construction a new divertor test tokamak (referred to as DTT) focused on exhaust issues.

In the field of materials (mission 3), beside numerous scientific advances, a preliminary engineering design of IFMIF-DONES has been completed, and a potential European site has been identified.

Fundamental to the European DEMO design development strategy (missions 4-7) has been the establishment of a baseline architecture that integrates all the major DEMO sub-systems into a coherent plant concept. This provides a framework to find holistic designs that are consistent with the DEMO stakeholder requirements and thus reveal the extent to which current plasma, materials, component and systems performance are adequate. The implementation of a philosophy of integrated design and a 'systems orientated' approach represents a significant advance over anything achieved previously. It has brought much greater clarity to a number of critical design issues, and the overall integration challenge. This includes: (i) identification of critical interface issues, project risks and innovation opportunities; (ii) establishment of an 'integration culture'; (iii) system optimisation studies.

A major highlight of mission 8 has been the completion of the superconducting Wendelstein 7-X stellarator. Its commissioning and first years of operation exceeded expectations, demonstrating a strong base for future scientific exploitation and development of the stellarator.

References

1 European Research Roadmap to the Realisation of Fusion Energy, ISBN 978-3-00-061152-0 (Nov. 2018).