PROGRESS OF ITER AND ITS VALUE FOR FUSION

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1. INTRODUCTION

The ITER Project is progressing steadily, overcoming challenges based on a new project baseline, structured towards achieving its missions of demonstration of extended burn with a fusion gain of $Q \geq 10$, and the availability and integration of technologies essential for fusion reactors. ITER is the first-of-a-kind (FOAK) industrial-scale DT fusion device, far exceeding the dimensions and parameters achieved in current devices [1]. Improvement measures based on lessons learnt, risk & opportunity assessments and stepwise procedures must be efficiently adopted in manufacture, assembly, commissioning, operation, and also in licensing for ITER and therefore beyond ITER. The role of the ITER project is to move fusion development forward from science to industry.

2. AVAILABILITY OF KEY FUSION TECHNOLOGY ALREADY ESTABLISHED BY ITER

Significant progress of FOAK manufacture of fusion components has been led by the ITER Organization (IO), the seven members' Domestic Agencies (DAs) and their national industries. For example, manufacture of all 19 Toroidal Field (TF) coils, all 6 Poloidal Field coils, and 4 (out of 7) Central Solenoid modules has been completed [2,3]. It can be concluded that a global supply chain and mass production of ITER-grade superconducting magnets has been established across the world. The prototypes (inner-target, outer-target, dome, and cassette body) of the tungsten (W) divertor that receives a huge amount of heat load have been manufactured, after successful confirmation of high heat flux tests [4]. Related mass production of W mono blocks and plasma facing units has been established. Under the ITER Project, manufacture of the high power Gyrotron system in the frequency range of 170 GHz has also been established [5,6].

The plant support systems (such as the power supply systems, the cryogenic plant, and several cooling water systems) have been largely commissioned. The world's largest cryogenic plant has started liquid helium production at ITER.

3. FOAK FUSION DEVICE CONSTRUCTION AND PREPARATION FOR OPERATION

Repair work of the Vacuum Vessels (VVs), which had geometric non-conformities in the field bevel joints, has started, based on successful R&D of an optimized combination of build-up and machining [7,8]. Two VV sectors have now been repaired and the sector sub-assembly with TF coils has started, following the schedule of the new baseline. Repair and re-manufacture of VV Thermal Shields, which show chloride stress corrosion cracking and galvanic corrosion defects, is also progressing according to schedule. The new tokamak In-Pit assembly procedure, based on the simultaneous welding of all the 9 VV sectors after positioning in the pit has also been adopted. The established tokamak construction plan up to the cryostat closure is a technically feasible plan including VV, in-vessel and ex-vessel assembly works [9] with newly designed assembly systems [10]. The construction is progressing on schedule.

Proceeding assembly and preparing operation, extensive discussions have been held with the French nuclear safety authority (ASNR) to restore trust and to evaluate strategies for enhanced safety demonstration accompanying ITER's licensing as a fusion device.

Superconducting Coil Cold Testing will start at the completed cryogenic plant from fall 2025. At the Neutral Beam Test Facility (NBTF), operation of SPIDER (the world's most powerful negative ion source) and commissioning of MITICA (a full-scale prototype of the ITER neutral beam injector) are underway [11].

Significant advancements have been also made in the design and integration of the Test Blanket Systems (TBSs) [12-16]. These efforts have enhanced understanding of the system's complexity and its integration, taking into consideration the space constraints, particularly in the Port Cells.

4. FEASIBILITY AND ATTRACTIVENESS OF THE NEW BASELINE

In 2024, the ITER Council endorsed the overall approach of the ITER New Baseline (Fig.1) with the main target dates of cryostat closure in 2033, start of DD H-mode operation in 2035, full plasma current I_p=15MA and toroidal field of 5.3T operation in 2036, start of the DT phase in 2039 and Q>10 in 2044. This New Baseline is a comprehensive and feasible plan for assembly, integrated commissioning and operation, developed to keep the already agreed final project goals and to deliver the key objectives of ITER as early as possible. It takes a stepwise safety demonstration and licensing approach. The first operation phase, named Start of Research Operation (SRO) phase, is a scientifically meaningful research phase with sufficient heating power of 40MW ECH and 10MW ICH,

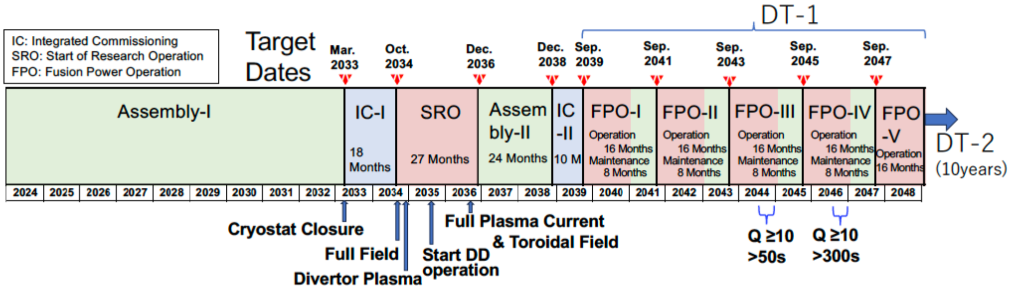

Figure 1: The overall approach of the ITER New Baseline 2024 with the main target dates

tungsten (W) water cooled divertor, and in-vessel coils for starting DD H-mode operation and for demonstrating the integrated fusion system with the nominal magnetic energy at I_P=15MA. This SRO phase will largely demonstrate ITER's mission of an integrated tokamak system at an industrial scale. This New Baseline was developed based on the most up to date scientific knowledge. One of the consequences is the change of the first wall armour material from Beryllium (Be) to W [17,18], because Be armour bridging phenomena during disruption and the resulting high electromagnetic forces are now understood. Other reasons include the toxicity and the large amount of erosion of Be, and the fact that DEMOs use W as the standard for their first wall. Although intensive evaluations have been conducted worldwide on the adverse effects of the high-Z W first wall on plasma performance, no show stopper has been found to date. Of course, risk mitigation is necessary. Now extensive works are being carried out on the design and fabrication of the W first wall [19,20], W material characterization [21], modellings, experimental evaluation in world tokamaks for the W wall behaviour and boronization for wall conditioning [22-25]. For the new baseline, the new ITER Research Plan (IRP) has been developed by the 7 Members, co-elaborated with input from the world fusion community and current research of tokamak devices [26]. In order to proceed this IRP reliably and effectively, we are developing the ITER plasma diagnostics [27-31] and the disruption mitigation system [32]. Development of integrated / advanced modellings and plasma prediction using them are also extensively carried out covering the core – pedestal – SOL – divertor, fast ions, disruption and runaway electrons etc. [33-40].

5. FOR FUSION WORLDWIDE

As we move towards DEMO, it is extremely important to 'evaluate' ITER through component manufacturing, tokamak assembly, operation, and experiments. ITER has started to contribute to the establishment of fusion codes & standards and fusion regulation. ITER is also serving as a platform for the development of next generation fusion human resources and supporting private fusion companies.

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