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Fusion technology development to ensure ITER deliverables –Indian experience

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In order to meet the commitments for the first plasma at ITER, all the domestic agencies are putting in considerable efforts to ensure the manufacturing and delivery of their commitments. Many of them are first of its kind components in terms of the sizes, technologies involved, performance requirements, compliance with ITER's nuclear safety requirements and the need to survive the lifetime of ITER with minimal maintenance. Managing non-conformities during these developments is another important activity to ensure compliance of the components with ITER norms of quality, safety and operation life time. In this paper, the Indian experience, on the above context, in ensuring the deliverables for the first plasma and the next operational phases, is presented. The material and engineering needs of these packages has been addressed through several prototypes which helped to establish ITER compliant fabrication procedures with tight tolerances for exceptionally large and complex components [1]. Further in order to enable demonstration of ITER desired parameters for packages like the RF systems and the power supplies, ITER-India laboratory with designated test beds has been established. In the specific case of diagnostic neutral beam, DNB, INDA has volunteered to test a full scale beam line, INTF, to supplement the ITER efforts in the R&D of Negative Ion Beams for ITER application and to help generate the desired database for CXRS diagnostics. Since its inception, the roadmap to ITER deliveries has been ensured through facility enhancement and research and development involving a large number of Indian research institutes and industries. In the areas where the services of foreign vendors have been utilized in-keeping with the ITER time line, parallel efforts with the Indian industry and institutes have been initiated to achieve self-reliance and explore new processes and techniques compatible to the nuclear devices.

Fabrication of the in-wall shields with ITER qualified corrosion resistant borated steel is nearing completion with ~90% of the required being delivered to the KODA and EUDA. The ITER grade CuCrZr material developed in collaboration with NFTDC Hyderabad with an elemental control of Cr –0.6 –0.8%, Zr : 0.07% to 0.15%, Cd: 0.01% and Co : 0.05% and with total impurities not exceeding 0.1% is a widely used material for high heat flux, 10 MW/m2, facing components of the diagnostic beam line. The area of heavy engineering coupled with extensive distortion controlled welding , has been demonstrated in the fabrication of the cryostat. Profile requirements of the order of 35 mm per segment for 60o segments of the upper and lower cylinders of the cryostat and 90 mm for the base section of the cryostat have been achieved. The base section of the cryostat has been completed and handed over to the ITER organization for the next step activities. Fabrication of the lower cylinder and the upper cylinder has also been completed in the workshop in ITER. The Top Lid is in its final stages of manufacturing, in the Indian industry, this shall be followed by the last action of Top Lid assembly in the ITER work shop. Example of precision engineering is evidenced in the development of first of its kind prototype of the multi aperture grid segment with angled beam groups for the DNB system. Following this, the 12 segments for the 3 grid DNB extractor and accelerator system have been manufactured. The process qualification of the manufactured segments required hot helium leak tests (HHLT) for the case of electrodeposited plasma grid segments at operational temperature of 150 oC and test pressure of 25 bar. In the absence of any data base and relevant codes and standards the process of performing the specific test has been established and can be applied to several components of the machine which work at high temperatures and pressures.

Welding of similar and dis-similar materials, using various welding techniques, has been developed to ensure fully inspectable welds compliant with ITER desired codes and standards. The highlights are the development of full penetration weld of two plates of thicknesses 190 mm and 105 mm with a flatness of 7 mm for the 40o segments of the cryostat. In addition, electron beam welding required for similar material, CuCrZr-CuCrZr, and dis-similar materials CuCrZr-SS through a nickel interface has been successfully used in the production of several components of the neutral beam system. Special NDE techniques using a combination of RT and water submerged UT have been developed to characterize electron beam welds in partial penetration joint configuration to ensure such configurations surviving ITER's life time under cyclic loading. To address to welding issues in space constrained environments, a special internal bore welding torch has been developed. Lip seal welding to comply with the safety requirements has been prototyped on a ~10 m perimeter weld length using remotely operated laser with seam tracking features. Thick metal coatings, ~1 mm thick Mo coating on Copper for RF ion source for DNB, using explosion bonding and laser assisted metal cladding etc. has been developed and characterized on prototypes.

Experiment on the test beds have helped establish deliverable parameter space related to RF, beams and power supplies. The requirement of 2.5 MW/VSWR 2:1/35-65 MHz/CW RF ions sources for the ITER ICRF system is the first of its kind in terms of power, duration and bandwidth specifications for which no high power tube exists worldwide. The proposed RF source is a combination of 2, 1.5 MW amplifier chains and a combiner circuit at the output side. Prototype experiments in the ITER India laboratory have helped to establish a vendor for RF tubes meeting the specifications of 1.5 MW/2000s/35-65 MHz/VSWR 2:1. A suitable combiner has been developed in-house and will be characterized to combine outputs from 2 amplifier chains to demonstrate the desired parameters. The development of accelerated negative ion beams for the neutral beam systems continues on the single RF driver based ROBIN and two driver RF based TWIN source test beds with an emphasis to reduce Cesium consumption and control the electron/ion ratio to the minimum possible. This experience is of extreme importance towards establishing the beam parameters on Indian test facility (INTF) expected to go into operation in 2021. In the area of multi-megawatt power supply development, indigenously developed 100 kV, 7.2 MW acceleration power supplies for the beams are fully operational on the SPIDER test bed in RFX Padua Italy.

India's participation in ITER has led to development of several areas of fusion technologies while ensuring time bound deliveries. The manufacturing of the cryostat, in-wall shields, several parts of the cooling circuit, the cryolines and the cryodistribution system is nearing completion. Several components have been delivered at ITER site in line with the first plasma schedule of ITER. The components related to remaining packages are in advanced stages of manufacturing and testing. Details related to the above technology developments, lessons learnt and present status of ITER deliverables shall be presented and discussed.

[1] A.K. Chakraborty et.al. Progress of ITER-India activities for ITER deliverables—challenges and mitigation measures, Nuclear Fusion Vol 59, No. 11, 112024

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