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National Institutes for Quantum Science and Technology
Toshiba Corporation

【Development of the ITER superconducting toroidal field (TF) coils】

The ITER superconducting magnet system is a massive assembly approximately 30 meters in diameter and weighing about 10,000 tons. The D-shaped toroidal field (TF) coils, 18 of which are arranged in a ring, generate the magnetic field required to confine the plasma (Figure 1). As one of the most important components of ITER, the reliability of the TF coils is essential to the project's success. Japan was responsible for manufacturing 25% of the TF conductors, all 19 TF coil structures, and 9 of the 19 TF coils.

A TF coil is a large superconducting magnet measuring approximately 16.5 meters in height, 9.2 meters in width, and weighing 310 tons. Each coil consists of a winding pack, which generates magnetic fields of up to 11.8 tesla, and a supporting structure that withstands electromagnetic forces of up to approximately 60,000 tons acting on the inboard side of the coil (Figure 2). The winding pack is made up of seven stacked Double Pancakes. Each Double Pancake consists of a D-shaped superconducting conductor and a radial plate with grooves that hold the conductor in place. The niobium-tin (Nb_3Sn) superconducting conductors used for the TF coils were manufactured by six ITER members: China, Europe, Japan, Korea, Russia, and the United States. The conductors produced by these members, together with the TF coil structures, all 19 of which were manufactured by Japan, were transported to TF coil assembly sites in Japan and Europe. They were then assembled into the completed TF coils.

In 2008, Japan signed a Procurement Arrangement with the ITER Organization for the supply of TF coils. In close cooperation with Japanese industry, QST spent approximately 15 years developing and manufacturing the coils, successfully completing all 9 TF coils assigned to Japan in 2023 (Figure 3). At the start of the project, many experts considered the TF coils to be one of the most challenging components of ITER. Nevertheless, researchers, engineers, and manufacturers across Japan took on the challenge with a shared commitment to realizing fusion energy. The project required a series of major technological breakthroughs. These included achieving millimeter-level precision in the fabrication of extremely large components, developing superconducting technology capable of stably carrying 68,000 amperes under a strong magnetic field of 11.8 tesla, and creating electrical insulation materials capable of withstanding radiation. Through years of dedicated research, development, and manufacturing efforts, each of these challenges was successfully overcome.

The development of TF coils was far more than a manufacturing project. It was a major engineering challenge that combined a wide range of advanced technologies, including large-scale and high-precision fabrication, cryogenic engineering, high-current operation, and high magnetic fields. The successful completion of the TF coils is an important milestone for the ITER Project and a testament to the technological capabilities developed through this international effort. The expertise and technologies established through this effort will provide an important foundation for the realization of future fusion energy.

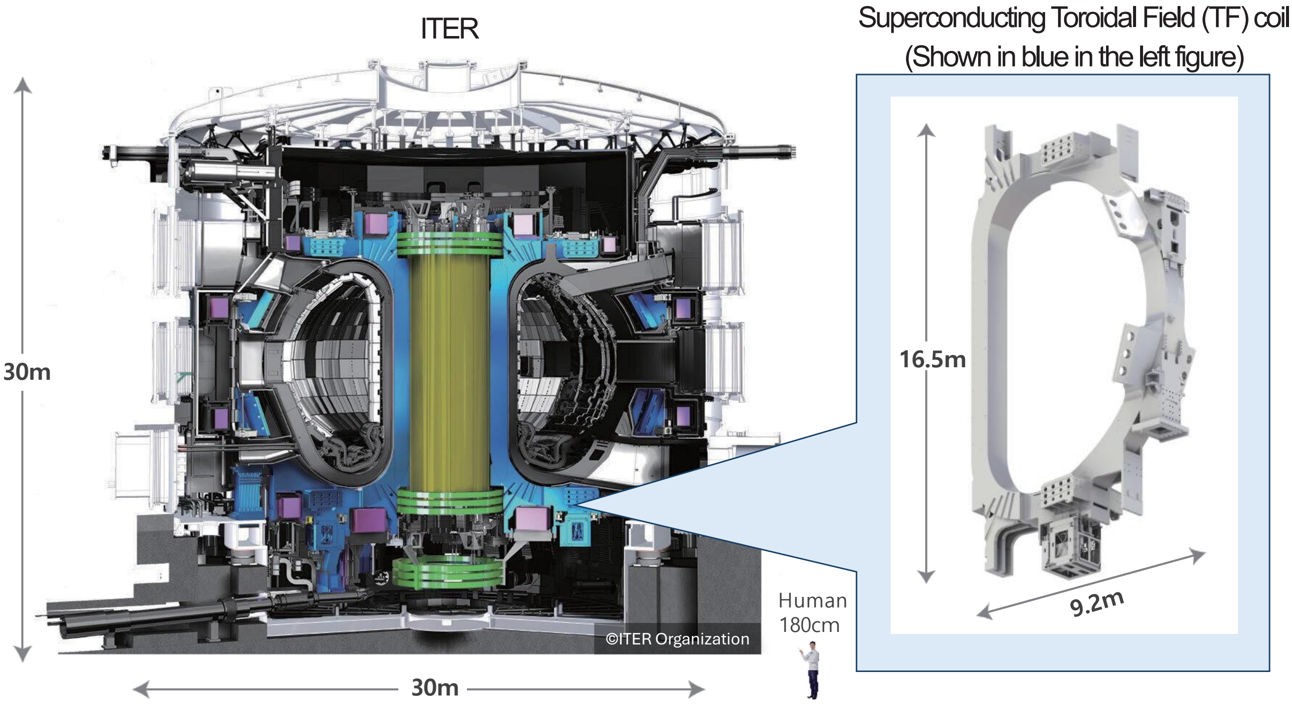

Figure 1. ITER and TF coil

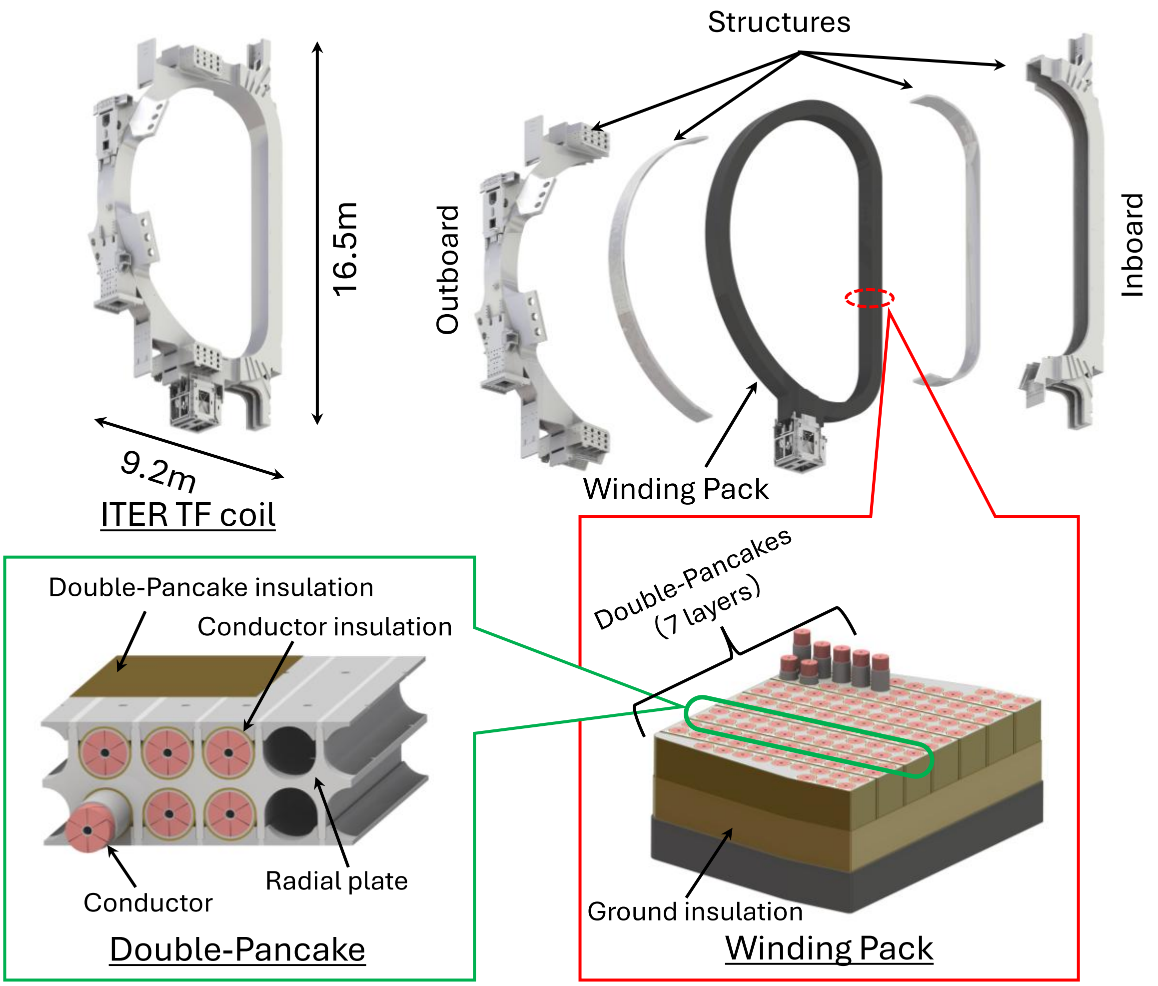

Figure 2. TF coil configuration

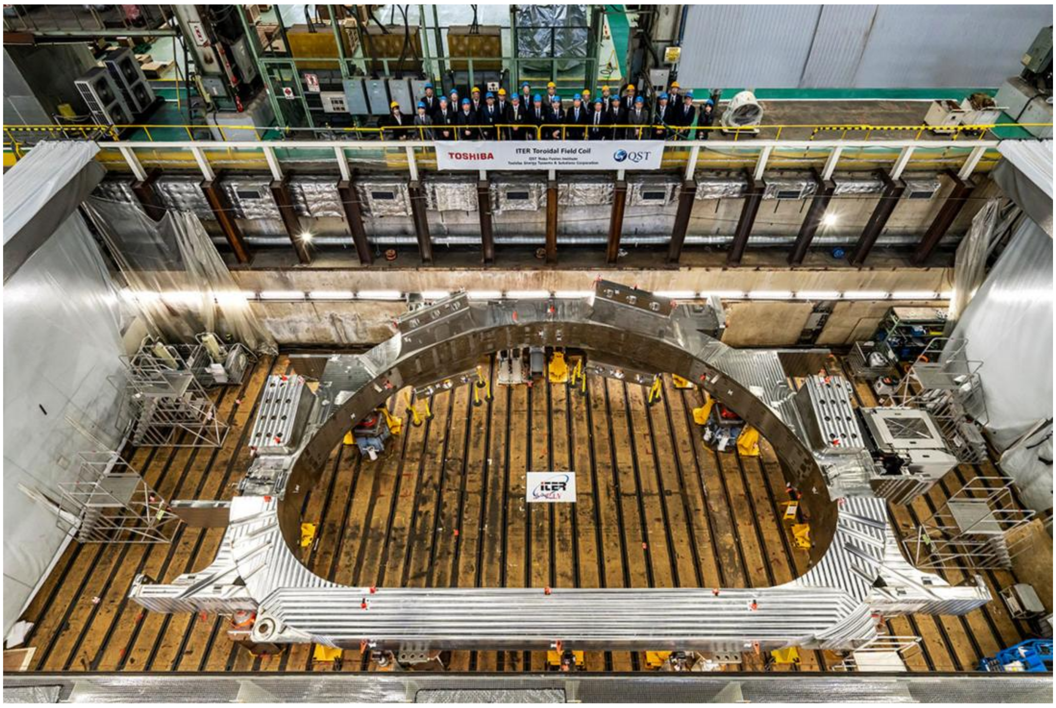

Figure 3. Completed TF coil

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