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Recent Research

ITER Blanket Shield Block successfully developed to protect a nuclear fusion reactor from ultra-high temperature plasma

- ITER Korea DA succeeded to manufacture the first product of a blank shield block

The first product of the International Thermonuclear Experimental Reactor (ITER) "Blanket Shield Block" has been successfully manufactured in Korea. It is designed to protect nuclear fusion reactor devices from plasma whose neutrons and more than 100 million °C temperature can damage the parts.

First product of ITER blanket shield block

"The ITER Blanket Shield Block is a primary barrier to protect the ITER devices from plasma's neutron damages and enormous energy set from ultra-high temperature over 100 million °C. Like a blanket, it protects all the main components such as vacuum vessel, magnet and so on" said Sa-Woong Kim, the team leader. In other words, it is the part to shield major ITER devices from plasma and neutrons from nuclear fusion, and is to be installed in puzzle-like connections, surrounding the inner wall of the vacuum vessel. Total 440 blanket shield blocks are going to be installed at ITER, procured by South Korea and China each to supply 220 units.

ITER Korea Project Blanket Technology Team members including Byung-Il Park(senior engineer), Sikun Chung (senior engineer), Hee-Jin Shim(principal researcher), Sa-Woong Kim(principal researcher, team leader), starting from left

This achievement is remarkable in that the team has successfully resolved technical issues which they have encountered in every stage, including design, manufacture and testing. They have successfully met the high standards required by ITER and have established mass production system for the blanket shield blocks.

Mission 1. Finding the best material and design: Stainless Steel

ITER put forward strict standards in selecting and manage the block materials. This was the first to meet for the production of blanket shield blocks.

"Good quality is essential for shielding from neutrons and for cooling plasma. It must be a low-radiation material with a short half-life when exposed to neutrons. On top of that, drilling and welding must be made possible to serve as a part to prevent plasma heat," commented Hee-Jin Shim, the principal researcher of the team.

Accordingly, the researchers first of all worked on developing a special stainless steel (i.e. 316L(N)-IG) for the blanket shield block to withstand extreme environments, which succeeded in satisfying all the strict criteria of ITER. Next, the design was completed in such a complex form considering, on the one hand, the shape of plasma inside, and on the other hand, all coils and pipes outside to tightly adjoin vacuum vessel.

"We had to wait till finishing the design of ITER vacuum vessel to start designing blanket shield blocks in earnest. This is because we had to consider the blanket shield blocks' location which is internally adjacent to plasma and externally to the vacuum vessel. The shape of blanket shield blocks was decided based on ITER's idea of the most stable plasma form and by the location of coils and pipes inside the vacuum vessel," said Dr. Kim.

Mission 2. Carving 'Stainless Steel 316L(N)-IG' as elaborately as if it were made of clay

In the production stage, a technique to delicately process difficult-to-machining materials of large size was developed to enable complicated shapes.

"First of all, we introduced a precision drilling equipment to make a path of cooling water into the stainless steel 316L(N)-IG which weighed around 5 to 6 tons. And the cover plate was welded precisely by welding craftsmen. Then, we finished machining the external into complicated shapes by a large precision-machining-device which can move both horizontally, vertically and tilting as well" said Sikun Chung, a senior engineer of the team. It was a challenge of carving very huge, sturdy surface with a very fine knife.

Drilling was another challenge to create a path for coolant. One shield block, whose size is 1m in height, 1.4m in width and 0.4m in thickness, requires as many as 220 drillings to create coolant passage. For the smooth flow of coolant, a hole of 1.4m length must be drilled through by one single drilling without mistake. If the way is drilled from both ends of the shield block towards the middle point, even a tiny miss of the point will lead to slow down the water flow on the spot, causing turbulence and drop in cooling performance. Therefore, it must penetrate 1.4 m with one single drilling, not to mention all the 220 coolant paths drilled inside a blanket shield block must meet each other accurately within 1mm tolerance.

Senior engineer Byung-Il Park explained the difficulty of drilling as follows:
"The 1.4 m should be drilled in one way within a 16-32mm diameter. Stainless chips from drilling may interfere with the way, and the drill may go astray due to the collision of power between the stainless steel and the drilling. We gathered initial mistakes and errors to come up with the best processing method. The ways in and out for coolant were finished by welding approximately 55 pieces of cover plate. Another trial and error was inevitable in welding as well to minimize distortion while welding total 160 meters."

In addition to the initial trials and lessons, the partnership with domestic companies also enabled engineers to find the best processing method.

The blanket shield block passed a non-destructive test designed to fully inspect for all welds. By using the world's first developed ultra-high temperature helium leakage test facility, it also proved its performance by completing ITER-like operation test under high-temperature, high-vacuum conditions.

Dr. Kim recalled that the various performance tests of the blanket shield block were like a series of endeavors trying to find something invisible. In particular, regarding the high temperature helium leakage test, the lack of both such a device and such experience demanded countries participating in ITER to gather for workshops to find a breakthrough together. It is notable that ITER Korea DA successfully passed the stringent testing standards of ITER for the first time among ITER members, with some of the technologies developed during the tests waiting for their patents to be approved.

Replacement of KSTAR plasma facing components

In 1995, South Korea announced it will build a medium size tokamak equipped with full superconducting magnets. Because no one has tried such concept before, it would be the first full superconducting tokamak in the world. 12 years later in 2007, South Korea reported the completion of the tokamak and started to operate the device. The world was excited to witness its first operation. Although they have no previous experiences on tokamak operation, Korean scientists ignited the sparks of plasmas successfully without failure. The temperature of KSTAR's first plasma was 2 million °C and the duration was 248 milliseconds. In 2019, after 12 years of operation, KSTAR achieved the driving record of 100 million °C plasma for eight consecutive seconds. The plasma temperature is 50 times higher and driving time is 30 times stronger.

To counter much stronger plasma operation, KFE plans to upgrade the plasma-facing materials inside of KSTAR from carbon to tungsten.

KSTAR has been using a high-purity carbon tile attached to the inside of the vacuum vessel to protect the device from events of sudden collapse of the high temperature plasma and from very high heat flux at the divertor. During the plasma operation, the temperature tiles rises to more than 1000°C due to plasma radiation and particle flux. Carbon tiles are frequently used in tokamaks due to their superior thermal properties and costs. Carbon is a low Z material which brings another advantage as a radiator that reduces the particle flux onto the wall.

However, carbon is chemically very active species with hydrogen forming hydrocarbon molecules such as methane (CD4) when plasma particles bombard the surface of carbon tiles. Methane formation in a fusion device causes problems because it contains four hydrogen per carbon atom resulting in the co-deposition of fusion fuel (D or T) as hydrogenated amorphous carbon film on the surface of remote areas inside the fusion device. Furthermore, methane entering into the plasma core degrades the performance of plasma, thus fusion reaction. The situation will be getting worse and worse as the plasma performance dramatically increases.

Inside the 'KSTAR' vacuum vessel of the superconducting nuclear fusion research device

In this context, the fusion communities are paying attention to tungsten as a new first wall material to replace carbon. With atomic number 74, melting point 3,422°C, boiling point 5,930°C, density 19.25g/cm3, tungsten, which means 'heavy(tung) stone(sten)' in Swedish, has the best melting point among existing metals. Therefore, it has excellent heat and chemical resistance, and there is little thermal expansion at high temperatures. Mass also reaches about 20g/cm3, which is 10 times heavier than carbon, making plasma-induced erosion very small.

Not only the ITER, but also Germany's ASDEX-U and China's EAST are replacing plasma materials with tungsten. KSTAR has launched a project to replace carbon a diverter, which plays a critical role in removing the heat and particle from plasma in the tokamak. Its goal is to complete the installation of new tungsten diverter by July 2022 in order to carry out high-performance plasma experiments and research related to DEMO reactor. The life time of tungsten divertor in DEMO is approximately 2.5 years in which much stronger plasma experiments take place., it can be used without any replacements for two and a half years.

The development of tungsten bonding technology is another big challenge. Two different materials, tungsten and copper, have to be bonded in order to sustain erosion by plasma (tungsten) while the heat load on the surface of the tungsten has to be removed by copper with flowing water. Since the properties of the two materials are so different and the thermal expansion rate varies by four times, high-level bonding processes are needed. Since 2012, KFE has promoted tungsten research and developed its own technology for bonding tungsten and copper alloys (CuCrZr).

Completion of a supercomputer to solve the challenges of commercializing fusion

- Research on nuclear fusion simulation leveraging 1PF high-performance supercomputer

KAIROS


Kraken, NFRI's first supercomputer, which retired in January this year after 10 years of challenges and achievements

The first project chosen by Aurora, the first exaflops-class supercomputer in the U.S., which can calculate 1 quintillion floating point operations per second in 2018, was the Princeton Plasma Physics Research Institute (PPPL)'s artificial intelligence (AI) project for nuclear fusion research. The fact that the world's top-notch supercomputer is planned for the nuclear fusion study indicates how significant and challenging nuclear fusion research is.

Though supercomputers have been globally mobilized, nuclear fusion research is yet to be realized on Earth for commercial purpose. This is because predicting the movement of plasma particles of more than 100 quintillion per unit volume in tokamaks and finding optimal operation conditions with proper control is not an easy task even with supercomputers.

This is not the first supercomputer that has been introduced in KFE. NFRI(KFE's previous name) introduced the 60 teraflop-supercomputer "Kraken" in 2011 to understand and solve challenging issues such as plasma transport and turbulence. Although there have been research achievements in the fusion theory and modeling, including code development, which can interpret and analyze KSTAR plasma experiments, there have been limitations in accommodating the increasing computing resource demand.

The fusion plasma, of which temperature exceeds 100 million °C, can be modelled accurately by a five to six-dimensional kinetic model rather than a general hydrodynamic model due to its high temperature and torus-shaped magnetic field geometry. In addition, existing supercomputers are not powerful enough to prepare a 'Virtual DEMO' in which a virtual fusion device may be designed and verified for the development of fusion energy. This is where "KAIROS" would play a significant role in the future.

KFE is ready to search for a "best operating condition" with KAIROS, whose calculation capability per second is 25 times larger than the retiring supercomputer Kraken. In August 2020, 'KAIROS', a 1PF high-performance supercomputer, began a full-scale service for Korean fusion research.

KAIROS, the name given through a public contest, is an Ancient Greek word meaning the right, critical moment. While chronos, another greek word for time, means natural and continuous passage of time, kairos implies an "opportune moment or time for action". Since 1995, the KSTAR has been developed and upgraded and the research program has progressed continuously. KFE now seeks to take a critical step toward realizing nuclear fusion, by enhancing its soft power with KAIROS.

The theoretical performance (Rpeak) of KAIROS is 1.56 petaflops and the real performance (Rmax) measured by HPL benchmark is 1.01 petaflops. It is the largest in Korea among the supercomputers dedicated to a specific research field. KFE plans to use KAIROS to develop and extend simulation codes to fully analyze and predict results of the ITER experiments that will begin operation in 2025. Furthermore, it will be used to develop virtual fusion devices that are geared for efficient and reliable design and verification of K-DEMO.

KAIROS aims to strengthen the soft power of the nation's nuclear fusion technologies and will be opened up to domestic fusion research communities including universities and industries, thereby help boost up the domestic nuclear fusion research capabilities.

Issues & Focus

Hyeon Park, the first Korean to win 'S. Chandrasekhar Prize'

Hyeon Park
(Former) Professor at UNIST Physics Department
(Former) Head of KSTAR Center
(Present) Senior Adviser to KFE

"I wanted to accurately capture the plasma to understand the physics therein."

- This has been a lifelong commitment of Dr. Hyeon Park, a world-renowned nuclear fusion scholar.

On September 10, the Plasma Division of the Association of Asia Pacific Physical Societies (AAPPS) announced Dr. Park, former head of the KSTAR Research Center and current KFE senior advisor, as the winner of the S. Chandrasekhar Prize. The S. Chandrasekhar Prize is considered one of the top three academic awards in the field of Plasma Physics, along with the James Clerk Maxwell Prize for Plasma Physics of the American Physical Society (APS) and the Hannes Alfvén Prize of the European Physical Society.

Secondary imaging observation has become an integral part of nuclear fusion plasma physics research

Working at PPPL, in 2002, Dr. Park succeeded in developing high-speed 2-D microwave imaging cameras with the support of the U.S. Department of Energy. This could show the movements of electrons inside plasma and, therefore, the 2-D imaging of fluctuating temperatures and densities of electrons within plasma, which allowed everyone to observe the same phenomenon objectively.

He moved to POSTECH in late 2007 when Korea's nuclear fusion research was about to begin in earnest. At that time, Korea was ambitiously trying to launch nuclear fusion research by building KSTAR. The imaging device developed by him enabled KSTAR, the world's first superconducting tokamak, to outperform as well as the matchless diagnostics.

"KSTAR's superb performance enabled symmetrical, high-performance plasma operation. This provided me with a chance to establish what I had been working on with great interests. I was able to sort out the controversies existing on the sawtooth crash process."

The identification of sawtooth crash process in the core of plasma is one of his representative achievements in the field. Sawtooth crash process was first discovered in 1974, and no consensus had been reached among researchers for almost forty years, until Dr. Park and his team at KSTAR conducted a series of experiments in accuracy to find the answer. "Previously researchers viewed plasma as cylinder-shaped, but KSTAR's imaging showed that plasma was not always shaped like a cylinder. In other words, the existing theory was half right, half wrong. It is not easy for a theoretical researcher to admit that his argument is wrong, but the images and videos provided a firm, objective ground for anyone to agree upon."

KSTAR is considered to be the most sophisticated and symmetrical superconducting tokamak in existence. Experiment results, conducted on this excellent device and supported by objective image data, have fueled new theories and modellings, which also allowed for KSTAR to develop and carry out world-class plasma researches. KSTAR's imaging device began 2-D measurements in 2008 and since has added 3-D imaging features to observe within all areas of KSTAR the process where magnetic fluid phenomena develop and collapse in both 2-D and 3-D simultaneously.

The opening ceremony of the Korea Institute of Fusion Energy, with the first president appointee, Suk Jae Yoo

The first president of
Korea Institute of Fusion Energy

Suk Jae Yoo has been appointed as the first president of Korea Institute of Fusion Energy(KFE) which will launch as an independent research institute. NFRI is to be promoted to KFE as of November 20, 2020, and the opening ceremony is going to be held on November 27 (Friday), participated by the Vice Minister of the Ministry of Science and ICT and key figures both from the industry and the academia.

Dr. Yoo received a bachelor's degree and a master's degree in nuclear engineering from Seoul National University. He later earned a doctorate in plasma science from KIT in Germany. He joined NFRI in 1999 as a researcher and has served as Director of the Plasma Technology Research Center, Director of the Applied Technology Development Department and currently as the president. His new term is three years from the 20th of November, the establishment date of KFE.

“In the new Korea Institute of Fusion Energy, we will shift our focus from basic research, which we have been conducting as a part of Korea Basic Science Institute, to core technology development crucial for commercializing nuclear fusion energy," said Dr. Yoo. He also added, "We will also reformulate goals and visions of the institution and prepare for a R&D framework to develop core technologies to build K-DEMO.” Within three months from taking the office, he will propose a research plan that further details the institution’s goals.

News Brief

EU/KO Collaboration on SPI Based Disruption Mitigation Systems Experiments Project Plan with CCFE & Eurofusion

In July, UK’s Culham Centre for Fusion Energy (CCFE) and Eurofusion signed a project plan with NFRI to provide KSTAR and JET with a framework to cooperate on SPI-based DMS experiments. It will lay the groundwork for joint experiments and infrastructure. It will be effective for the next five years as a part of Korea-EU TMP research project which is subsequent to the Agreement for Cooperation between European Atomic Energy Community (EURATOM) and the Government of Republic of Korea in the Field of Fusion Energy Research. With NFRI’s promotion to KFE, KFE will take over this project along with all agreements of NFRI to carry out nuclear fusion research on behalf of Korea.

Upcoming Event

Korea-China, Korea-Japan JCM to be held in Korea

Every two years KFE hosts the annual bilateral meetings for cooperation in fusion energy research with China and with Japan. The JCMs, which are held alternately between Korea and each country, have been postponed this year due to COVID-19 and will be held online in December. In the upcoming JCMs, agendas such as KSTAR cooperation, ITER technology cooperation, nuclear fusion design cooperation will be discussed with distinguished scholars from China and Japan.

- Korea-China JCM: December 7(Monday) - 8(Tuesday) 2020
- Korea-Japan JCM: December 10(Thursday) - 11 (Friday) 2020

KFE KOREA INSTITUTE OF FUSION ENERGY
Website : https://www.kfe.re.kr/eng/index | **Email :** global@kfe.re.kr
Address : 169-148 Gwahak-ro, Yuseong-gu, Deajeon 34133, Republic of Korea