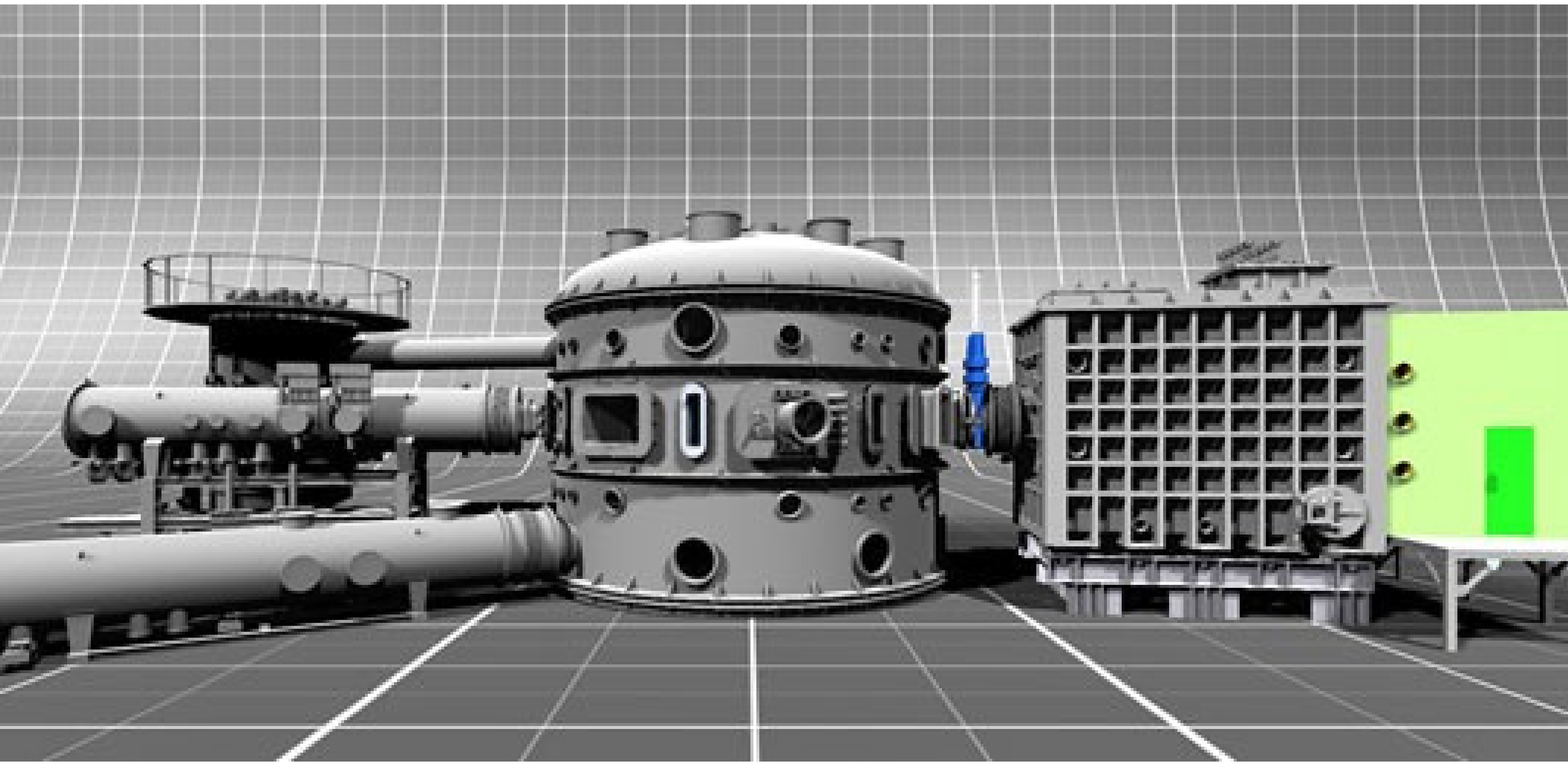
KFE NEWS

Vol. 30 | November 2021



A LEAP FOR FUSION SIMULATION TECHNOLOGY: PLANNING STUDY FOR V-DEMO DEVELOPMENT IN KOREA

Fusion technology development in Korea faces three primary challenges: (i) Development of a high-performance operating mode for Tokamak, (ii) Building a blanket test facility to bridge KSTAR, ITER, and a fusion demonstration plant (DEMO), and (iii) Utilization of experimental data along with the integration of scientific and technological achievements to design a fusion DEMO. To achieve these three missions, KFE conducted a planning study for the development of V-DEMO.

WHAT'S INSIDE THIS ISSUE:

V-DEMO will be a virtual fusion demonstration plant, built by applying the 4th Industrial Revolution technologies including supercomputers, artificial intelligence, big data, etc. The ultimate goal of V-DEMO is to quantitatively realize the core functions of a fusion power plant and comprehensively reproduce one by integrating simulations of tokamak, blanket, and BOP (Balance of Power) systems. With these features, V-DEMO can be used to identify various physical and engineering requirements that can be used in the detailed engineering designs of a fusion power plant. Clarifying these requirements can help in optimizing and verifying plant designs, as well as assisting security and safety clearance studies by investigating various accident scenarios.

Building V-DEMO will require examining available technologies and current technological levels, and then specifying strategies for each step. Therefore, the focus of this planning study was identifying the technological priorities required to resolve the challenges mentioned above.

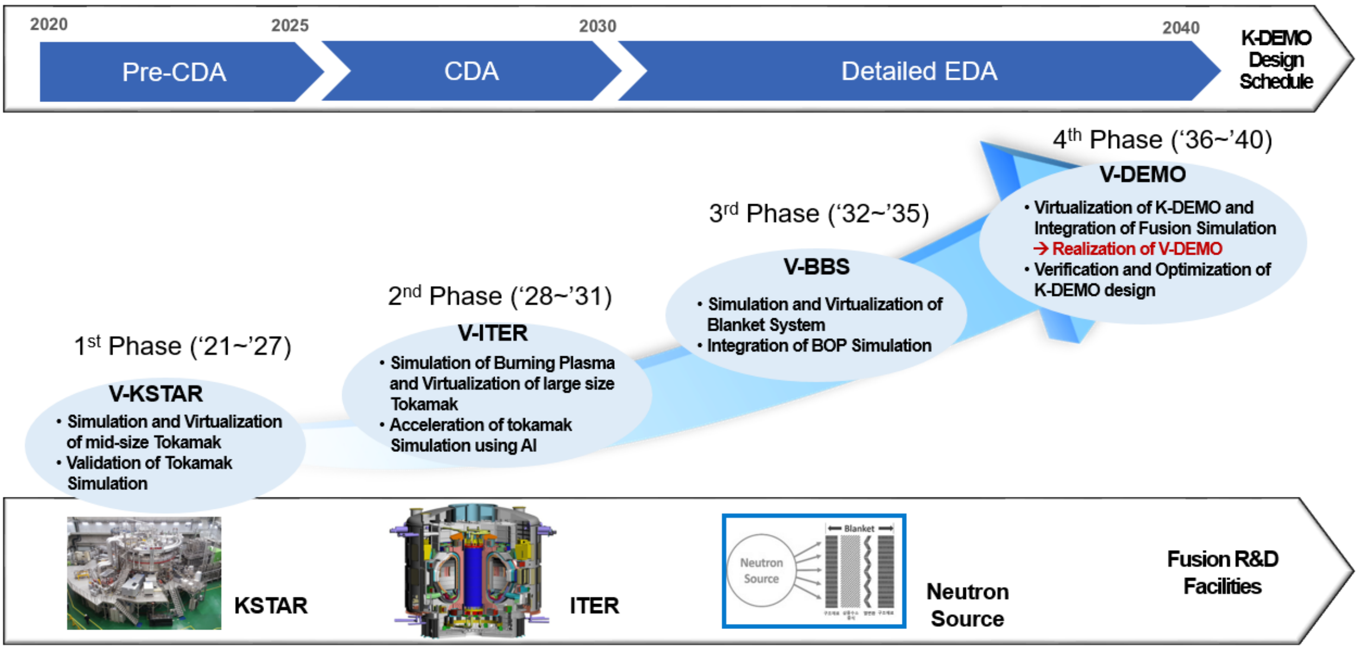
Technology development trends and development direction for V-DEMO

Fusion simulation is the core technology for V-DEMO. It has been under development for the last two decades, mainly focusing on core plasma, heating, and PMI (Plasma Material Interaction). The current mainstream technologies are large-scale simulations capable of parallel expansion over tens of thousands of CPU cores. Korean researchers are presently working to elaborate and verify simulations using KSTAR's advanced imaging diagnostics.

The global goal in fusion simulation development is to develop the capability to quantitatively predict experiments using supercomputer-based simulations, and relevant studies are expected to play a large role in KSTAR studies.

The core plasma in tokamak is connected to power facilities via a breeding blanket system, which converts fusion energy into electricity. Simulating fusion electricity generation involves both fusion and nuclear power studies. The former can take advantage of the latter. As a matter of fact, the TBM (Test Blanket Module) currently being tested in ITER uses nuclear analysis tools and safety analysis codes from the nuclear power community, demonstrating that nuclear simulation technologies can be expanded to enable V-DEMO's targeted functions.

AI (Artificial Intelligence) is also promising for fusion research innovation. AI can utilize machine learning based on numerous fusion experiments and simulation data to derive a data-driven fusion model. The big advantage of the data-driven fusion model is its combination of fast calculation and good precision. For example, according to research already published, a heating simulation can be generated in a much shorter time with machine learning, allowing real-time controls. Without it, the calculations would require thousands of CPU cores and considerable time. Various studies to accelerate simulations are ongoing, with the ultimate goal of developing a fusion simulator capable of the tremendous volume of repetitive calculations necessary for engineering design.



Roadmap for V-DEMO project

V-DEMO will need to integrate simulations from various fusion areas and therefore will need to develop **an integrated platform**. Fusion societies worldwide are working on simulation software integration frameworks. One of the most promising projects is the ITER-IMAS framework, which is currently under development for ITER. V-DEMO should expand its technological base to include plant features based on ITER-IMAS.

Digital twin is a technology that can be used to virtualize machines and facilities, using machine design data, and is considered the basis upon which simulation software and integrated framework can be deployed. For fusion, "Virtual KSTAR" is being developed to perform virtual experiments that combine KSTAR design, experimental data, and heating simulations. The technology developed through KSTAR will be applied to ITER in the near future, to pave the way for V-DEMO development.

Roadmap for V-DEMO development

Presently, various technological developments including simulations, virtualization, supercomputers, and machine learning are needed for V-DEMO development. In this planning study, a total of five technology groups were identified as the key technologies for V-DEMO: (i) tokamak simulation group, (ii) blanket-BOP simulation group, (iii) accelerated fusion simulation group, (iv) enabling technology group, and (v) fusion big data group. The development plans and strategies for each group were also established.

V-DEMO development will go through four stages by the year 2040. In the first stage, simulation and virtualization of a middle-sized tokamak such as KSTAR will be carried out. In the beginning, technology verification using KSTAR data will be the key objective. In the second stage, the

	1st Phase ('21~'27)	2nd Phase ('28~'31)	3rd Phase ('32~'35)	4th Phase ('36~'40)
Key Facility	KSTAR	KSTAR & ITER	ITER & Neutron Source	Neutron Source & K-DEMO Design
Key Target	• Tokamak Simulation • Virtual KSTAR	• Burning Plasma Simulation • Virtual ITER	• Blanket and BOP Simulation • Simulation Integration	• Validation of burning plasma simulation • Verification and Optimization of K-DEMO designs

Plan for experimental validations and key development targets in each phase

technologies from the first stage will be further developed for ITER, and simulation acceleration using artificial intelligence will begin. In the third stage, blanket and BOP simulation technology development will be performed in collaboration with the nuclear energy community. In the final stage, V-DEMO will be completed, integrating the K-DEMO design data. Verification and optimization of a demonstration plant will be carried out utilizing V-DEMO.

Fusion research in Korea has been ongoing for the last two decades, focusing on KSTAR and ITER. Now, another leap is needed to accomplish a demonstration of fusion technology. Alongside hardware technological achievements, another foundation for the fusion demonstration should be established, by proactively developing fusion simulation technologies, including V-DEMO.

NEWS Brief

KSTAR'S 30,000TH SHOT

Fourteen years after the first plasma was generated, the Korean artificial sun, KSTAR, has made its 30,000th plasma shot.

Three years ago on the 20,000th plasma shot of KSTAR Dr. Si-Woo Yoon, Director of KFE KSTAR Research Center commented, "There is nothing special. It is just another plasma experiment we have been doing routinely. We still have far to go," he said.

Such moderation was repeated for the 30,000th shot. The control room was just as calm as in previous campaigns when the shot was taken at 13:08 on September 17th.

During a yearly KSTAR campaign, forty shots a day are taken on average. Both domestic and international experts may participate in the experiments. Researchers across the world are allowed to apply for KSTAR experiment proposals, and the most pio-neering are selected.

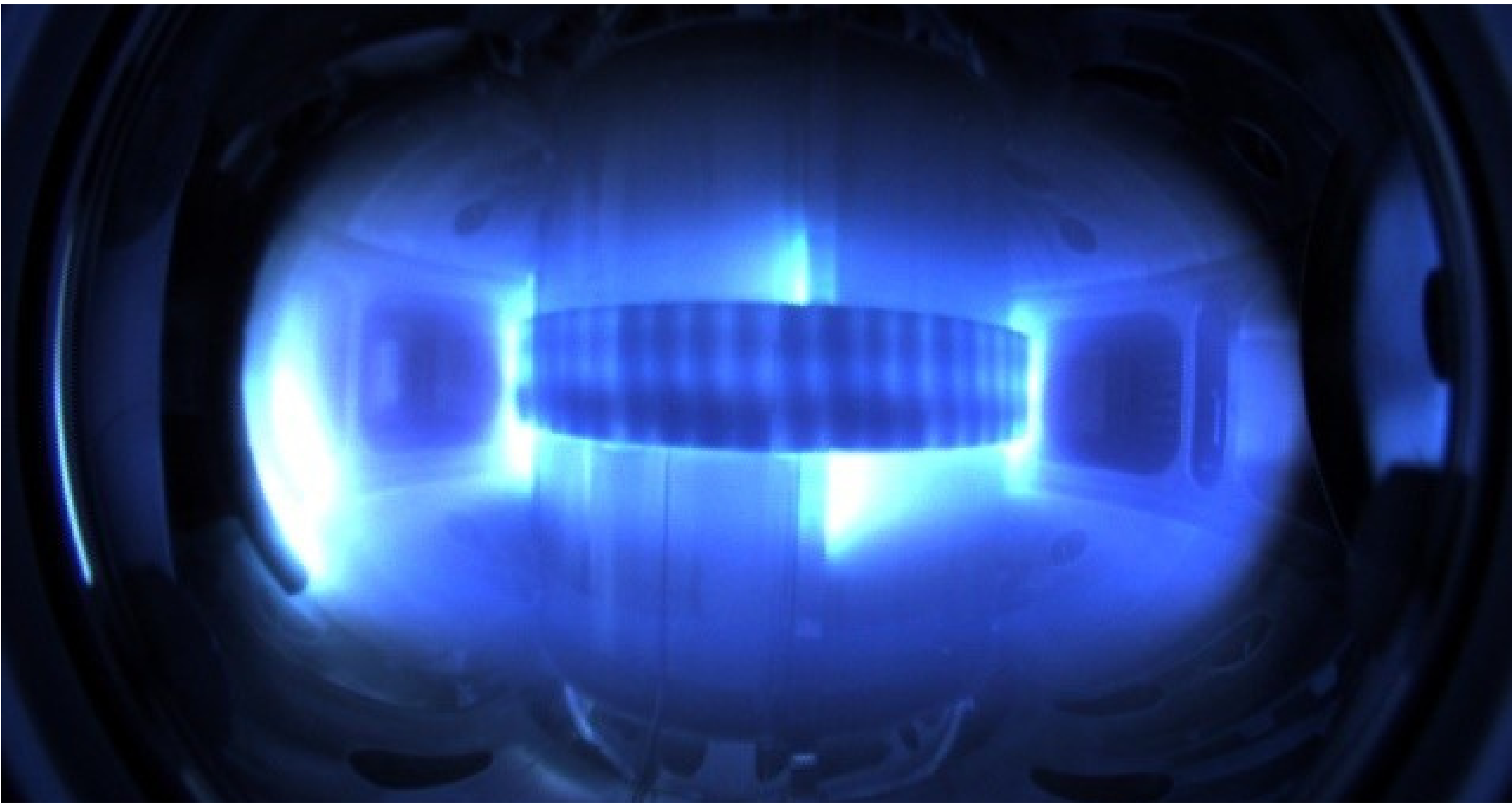
It begins everyday with the session brief meeting, where mainly two subjects are discussed: firstly, a brief review of yesterday's experiments, then a preview of today's experiment plans. Every shot has a different objective, which may provide new insights.

Experiments may go well, or not. But there is never a failure in KSTAR experiments. Even when an experiment doesn't end as expected, each study provides a new lesson that can improve understanding of the plasmas, and open new possibilities. In this sense, thirty thousand plasma discharges in the past mean thirty thousand new things that KSTAR has learned about the plasmas.

KSTAR Milestones

The first plasma in KSTAR, which lasted for 0.1 seconds, occurred in 2008, followed by the 10,000th in 2014, the 20,000th in 2018, and the 30,000th in September 2021 respectively. The steady progress over fourteen years of experiments has demonstrated KSTAR's stable operations, which have achieved important machine milestones.

In 2010, KSTAR achieved the world's first H-mode discharge in superconducting tokamak devices. Then in 2016, it operated in H-mode for seventy-two seconds, breaking the seemingly unbreakable wall of one minute for the first time in the world. Following that, another record was made by KSTAR in 2018, with an eighty-eight-second-long H-mode operation.



The first plasma of KSTAR in 2008

Also in 2018, KSTAR successfully heated the plasma ions up to one hundred million degrees, opening a new era of super-hot plasma operations. It extended the pulse length up to eight-second-long operation at one hundred million degrees in 2019, and then in 2020 for twenty seconds, breaking its world record for longest sustainment.

The twenty-second-long operation confirms KSTAR has been improving the performance in various metrics, i.e., plasma temperature, density, and confinement. It also symbolizes the future potential of a fusion plant which must run for twenty-four hours.

Beyond the 30,000th plasma shot

So far, KSTAR has advanced both plasma confinement and plasma performance. While the focus during the first ten thousand plasma shots was mainly on plasma breakdown and maintenance, the key issue for the second ten thousand plasma shots was the long-pulse operation of high performance plasma. Now, beyond the 30,000th plasma shot, KSTAR will explore new possibilities for fusion energy focusing on the sustainment of super-hot plasma. After completing its upgrade to a world-class Tungsten cassette divertor, it is expected KSTAR will be able to operate at much higher temperatures in longer pulse-length. KSTAR experiments will move on further, contributing to the operation of ITER and K-DEMO in the future.

KFE People

AAPPS-DPP YOUNG RESEARCHER AWARD WINNER IN KFE, DR. SANGHOO PARK

Dr. Sanghoo Park, senior researcher at the KFE Plasma Research Institute, has won the Young Researcher Award (U40) of the Association of Asia Pacific Physical Societies, Division of Plasma Physics (AAPPS-DPP).

AAPPS-DPP awards highlight young researchers conducting outstanding work that contributes to the plasma research field. Dr. Park was selected as one of the winners for his pioneering research on atmospheric pressure plasma.

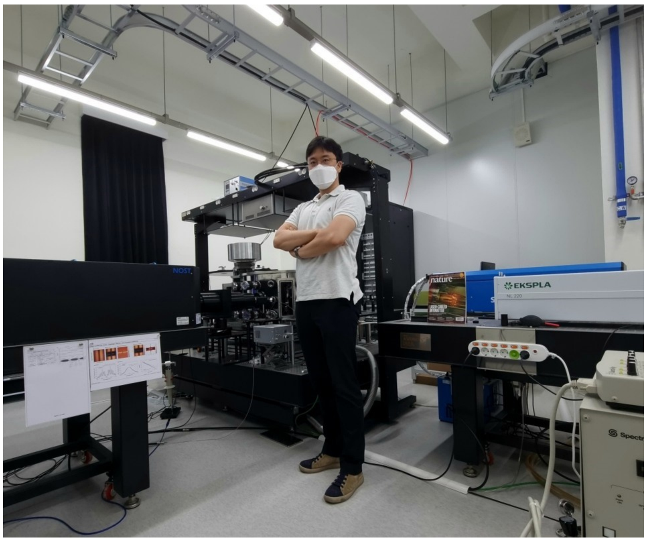
"Atmospheric pressure plasma is very interesting, because it can be applied in various industries," said Dr. Park, "such as energy, environment, semi-conductor, and biomedicine. While fusion plasma researchers are facing challenging tasks such as long-time plasma operation by controlling many types of plasma instabilities in tokamak plasmas, we atmospheric pressure plasma researchers are studying how to manipulate unstable plasma reactions in contact with gas and liquid."

He found that weakly ionized gas can increase fluid dynamic stability at the surface between a gas and a liquid. Through experiments, he revealed the cause, and then developed an economic, commercial method to control the phenomenon. According to his explanation, electric wind (also called ionic wind) and fast ionization waves, which are called the "plasma bullets", occur in a plasma jet. They can be manipulated to suppress instabilities in liquid surfaces. The plasma bullets cause a strong, tangential electric field, which renders the surface more stable.

The research was carried out as a collaboration project among professors at KAIST (Korea Advanced Institute of Science & Technology) and JBNU (Jeonbuk National University), and was published in Nature*. His other work revealing the key mechanism of electric wind was also published in Nature Communications.

**Title: Stabilization of liquid instabilities with ionized gas jet (Nature 592, 49-53)*

Dr. Park commented regarding his achievements, "Thanks to the KFE Plasma Research Institute, I was able to collaborate with experienced researchers and benefit from the advanced research facilities."



Dr. Park in Integrated Plasma Diagnostics Lab

"In KFE, experts from various fields are working together to experiment with novel ideas. The best results are archived into its database. We are also collaborating to figure out what are the core technologies to commercialize plasma technologies, and what we should do to develop them, even in basic research stages."

Dr. Park's work will be continued in the KFE's 'Integrated Plasma Diagnostics Lab'. Here, he is exploring the physics of plasma jets and electric winds, using plasma diagnostic systems equipped with various lasers and high-resolution cameras.

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