

1. Generic V-Lab

Progress Status as of FY2025

1. Overview

In this R&D theme, we are constructing a versatile V-Lab (the Generic V-Lab), which will serve as the foundation for virtual laboratories (V-Labs)—digital-space experimental environments—that can be applied across a wide range of fields. To achieve this, researchers from diverse disciplines, including AI and data-driven science, computational physics, mathematical sciences, and high-performance computing, are collaborating to develop methods for integrating experimental data, theories and models, and computational (simulation) data (Fig. 1). The Generic V-Lab is being realized by extending the “Open Data Analysis Tool for Science and Engineering (ODAT-SE),” a general-purpose data analysis framework developed previously by the PM (Hoshi) et al.

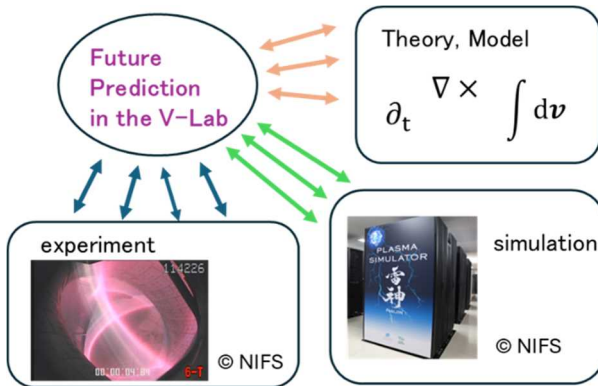


Fig. 1. Conceptual illustration of the integration of experiments, theories and models, and computational data that forms the foundation of the Generic V-Lab.

2. Outcomes as of FY2025

In FY2025, we primarily conducted research on essential technologies for the Generic V-Lab, including AI and data-driven scientific approaches and high-speed mathematical algorithms. We also developed a prototype of the Generic V-Lab by extending ODAT-SE and demonstrated its usefulness through applied problems (examples are shown in Fig. 2).

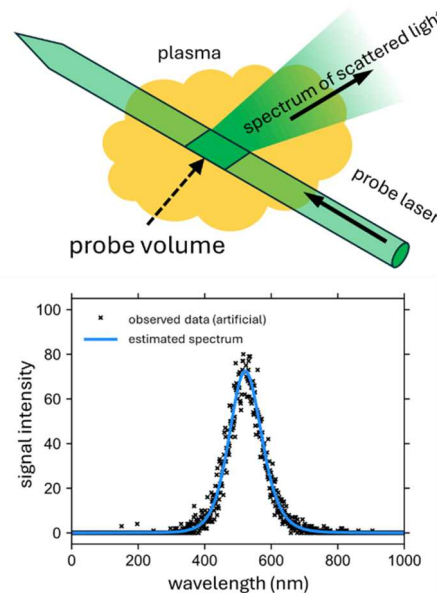


Fig. 2. Demonstration of the usefulness of the Generic V-Lab applied to Thomson scattering diagnostics: schematic image of the experiment (top), and comparison between measured (synthetic) scattering spectrum and the estimated spectrum (bottom).

The Generic V-Lab must be capable of supporting a wide variety of experiments simply by incorporating programs tailored to different experimental devices. In Fig. 2, we demonstrate its usefulness using the “Thomson scattering diagnostic system,” which is widely used in fusion energy research. This diagnostic system measures the velocity distribution of particles within a plasma. Our results show that the system can accurately determine particle velocity distributions even under complex conditions where particle motion is not uniform. Although ODAT-SE was originally developed for materials science, it has been expanded through this project to form the foundation of the Generic V-Lab, enabling its application to a wide range of experimental devices across multiple fields. This is the first time the framework has been applied to instruments in plasma science, and the work has demonstrated the versatility required for constructing various V-Labs.

3. Future Prospects

We will further advance the data integration methods for experimental data, theories and models, and computational (simulation) data (Fig. 1), thereby enhancing the capabilities of the Generic V-Lab. In parallel, we will collaborate with the principal investigators (PIs) of Research and Development Themes 2 through 4 to develop V-Labs tailored to diverse fusion energy systems as well as material experiments such as neutron irradiation (details on V-Lab construction are provided on the next page). As the project progresses, we plan to sequentially add new research and development topics and PIs.

2.3.4. V-Lab A, B, C

Progress Status as of FY2025

1. Overview

To realize practical fusion energy systems, various virtual laboratories (V-Labs)—digital-space virtual experimental environments—are required for next-generation devices and neutron-irradiated materials.

In this project, to demonstrate that fusion energy system design and performance testing can be carried out in the digital domain using V-Labs, we have established three research and development components, each dedicated to constructing an appropriate V-Lab: V-Lab A, B, and C. These V-Labs will serve as pioneering proof-of-concept examples showing that digital-space design and performance evaluation are feasible, and through industry-academia collaboration, the framework will be expanded to enable the development of even more diverse V-Labs.

- R&D Theme 2: for magnetic-confinement fusion energy V-Lab A systems
- R&D Theme 3: for fusion energy systems other than V-Lab B magnetic-confinement (e.g., laser fusion)
- R&D Theme 4: V-Lab for material experiments such as V-Lab C neutron irradiation

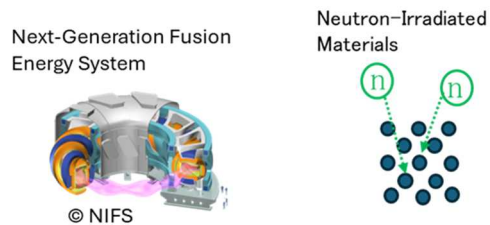


Fig. 1. Examples of target applications for the V-Labs: next-generation fusion energy devices (left) and neutron-irradiated materials (right).

2. Outcomes as of FY2025

To demonstrate that fusion energy system design and performance testing are feasible in a digital space, we formulated the standards (achievement criteria) required for V-Labs, selected principal investigators (PIs) responsible for constructing each V-Lab, and established the R&D structure. Specifically, we first organized workshops on magnetic-confinement fusion systems, non-magnetic-confinement fusion systems, and material experiments such as neutron irradiation—topics corresponding to V-Labs A, B, and C. Open discussions were held regarding the R&D challenges that each V-Lab should address, and based on these discussions, we defined the outlines of the R&D tasks.

Following this, based on the defined task outlines, we selected PIs responsible for constructing the V-Labs for magnetic-confinement fusion systems—specifically, tokamak-type (Fig. 2, left) and helical-type (Fig. 2, right)—as well as PIs responsible for V-Labs for material experiments such as neutron irradiation, thereby establishing the R&D structure. Furthermore, through detailed discussions with these PIs, we formulated the standards required for V-Labs. By constructing V-Labs capable of supporting the design and performance testing of different types of fusion energy systems, such as tokamak and helical devices, this project aims to explore the potential of diverse fusion energy systems.

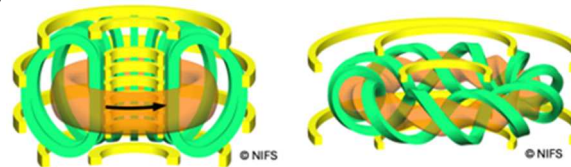


Fig. 2. Conceptual images of magnetic-confinement fusion energy systems: tokamak-type (left) and helical-type (right).

3. Future Prospects

Looking ahead, we will continue developing V-Labs for various fusion energy systems and material experiments such as neutron irradiation (Figs. 1 and 2), enabling the design and performance evaluation of next-generation devices and neutron-irradiated materials.

Each V-Lab will be realized by combining “dedicated modules” developed by PIs of R&D Themes 2–4—based on simulation programs, experimental data, and computational data used in the fusion energy field—with “common modules” developed by the PI of R&D Themes 1, leveraging expertise in AI, data-driven science, and mathematical sciences (Fig. 3). As the project progresses, additional R&D topics and PIs will be incorporated as needed.

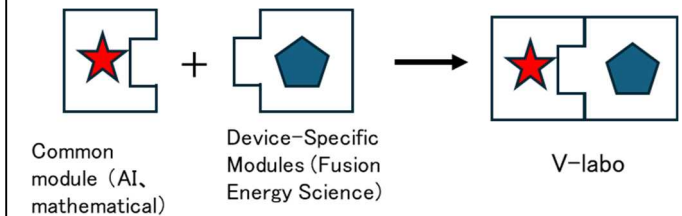


Fig. 3. Conceptual illustration of the structure of the V-Lab.