Innovation in the Formulation and Solution Methods of Mathematical Models to Transform the Paradigm of Fusion Research

Project manager

OZAWA Tohru

Professor, School of Advanced Science and Engineering, Waseda University

Leader's institution

Waseda University

R&D institutions

Waseda University,
Tohoku University

Summary of the project

Amid growing expectations for the early realization of fusion energy, no theoretical framework yet exists that can accurately predict the performance and characteristics of future fusion devices. The uncertainties that hinder naive forecasting or extrapolation from experiential knowledge stem from the nonlinear nature of ultra-high-temperature plasmas and the systems that generate and sustain them. Understanding nonlinear phenomena is a grand challenge shared by complex systems (non-integrable systems) such as weather, ecosystems, and the economy, and it represents a major frontier for the mathematical sciences.

In this project, plasma physics—as an experimental discipline (and, similarly, materials science for fusion-reactor materials)—will collaborate with the mathematical sciences to generate new mathematical concepts and methodologies. This effort will be grounded in concrete problems and supported by abundant experimental data and numerical simulations.

Historically, plasma physics has given rise to numerous mathematical developments—related to solitons, chaos, singular perturbations, and hierarchical structures. Building on these traditions, and with an eye toward close collaboration with rapidly advancing AI and data science, this project will begin by formulating core challenges in the fusion domain in precise mathematical terms. Through redefinition of key concepts and disruptive innovation in methodology, the project will contribute to the early realization of fusion energy as well as improvements in performance and safety. In addition, the project will actively promote interdisciplinary networking among early-career researchers participating in Moonshot Goal 10 (MS10), enabling them to discuss the future of their respective fields using mathematics as a common language, thereby contributing to the development of the next generation of talent.

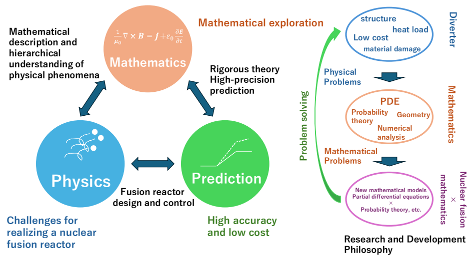

Fig. 1. Conceptual diagram of the R&D project

Milestone by 2034

We will implement a mathematically grounded theoretical framework for fusion-reactor development and establish mechanisms for its deployment, thereby contributing to the practical realization of fusion energy.

Milestone by 2029

We will solve mathematically formulated key problems in fusion-reactor development and construct a systematized theoretical framework. In parallel, we will elucidate the connections among modeling, numerical simulation, and control systems in fusion-energy technologies, thereby completing the foundational basis for the development of innovative fusion systems.

Project structure

In this project, we will first establish a community board composed of experts in fusion science and the mathematical sciences. After defining the key challenges to be addressed ("fusion problems"), the board will analyze and decompose these problems from a mathematical-science perspective, using mathematics as a common language. Based on this analysis, we will then assemble an optimal team of mathematical-science specialists to drive the development of solutions.

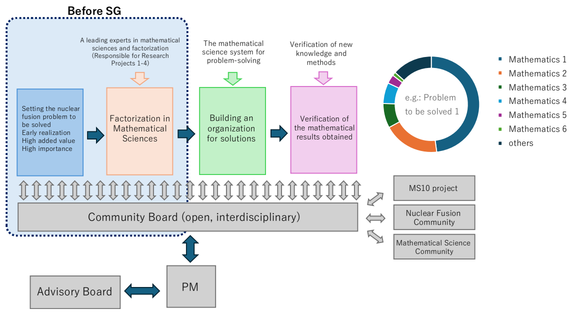

Fig. 2. R&D Framework.

Japan Science and Technology Agency