9. Department of Simulation Science

Fusion plasma is a typical complex system which is characterized by multi-hierarchy, nonlinearity, non-equilibrium, and openness. It consists of multi physics and multi time/space nonlinear processes, from macroscopic process, such as, plasma transport, all through to microscopic electron dynamics. For full understanding of complex phenomena in fusion plasma a holistic viewpoint is very important in addition to the investigation of fundamental processes in an individual hierarchy. Based on the recent remarkable development of the information technology such as supercomputer, network and visualization system, the conventional simulation research is now evolving to the new paradigm, “Simulation Science”, which will enable us to comprehend a multi-hierarchy system holistically.

The Department of Simulation Science (DSS) was established in 2007 with aiming to promote simulation science based on the studies of the dynamics of nonlinear, non-equilibrium, open systems, in which the fusion plasma system is centered. DSS consists of the Division of LHD and Magnetic Field Confinement Simulation, the Division of Fusion Frontiers Simulation, and the Rokkasho Research Center (Fig.1). Besides, the computer working group, and the virtual reality (VR) taskforce are organized to support activities of various collaboration researches.

There are two tasks in simulation science at DSS. One is to construct the simulation methodology and simulation environment that enables us to deal with the complex multi-hierarchy system consisting of multi time/space nonlinear processes and multi physics. The second task is to understand and systemize physical mechanisms in fusion plasmas and explore science of complexity in plasma as a basic research supporting fusion plasma studies by utilizing developed methodology and simulation environment. For these tasks three simulation projects, i.e., LHD and Magnetic Confinement Simulation Project, Laser Fusion Simulation Project and Plasma Complexity Simulation Project have been launched.

In the LHD and Magnetic Confinement Simulation Project, various researches on multiple physical processes and their mutual interactions occurring in core and edge plasmas are being done based on fluid and kinetic simulations aiming at the ultimate realization of the helical numerical test reactor. Influence of short-wave truncation of MHD/Hall MHD turbulence in the LHD plasma is studied by using the MHD and Hall MHD codes. The pellet ablation code (CAP) is used to clarify the dependence of pellet plasmoid motion on magnetic field configuration and its initial location in the LHD and Tokamak plasmas. An extended-MHD model is implemented into the MIPS code and the finite Larmor effect on the ballooning modes in the LHD plasma is examined by using the extended MIPS code. Nonlinear MHD effect on the evolution of the Alfven eigenmode (TAE) is investigated by hybrid and MHD simulations. The gyrokinetic Vlasov (GKV) simulations reveal new features in effective regulation of ITG turbulence by zonal flows in the neoclassically-optimized LHD configuration. A new GKV simulation codes, GKV-X, has been developed based on the original GKV code, to study full geometrical effects of non-axisymmetric field configuration on microinstabilities and turbulent transport. Monte Carlo simulations using the ERO code with a 2D model is done to study the impurity transport process in divertor-leg regions and the impurity deposition on surfaces of plasma confinement wall in LHD. The transport module in an integrated modeling code for three-dimensional configurations, TASK3D, is improved to reduce the calculation time and analyze the MHD stability limit in LHD under the collaboration with Kyoto University and the Department of LHD Project.

The Laser Fusion Simulation Project has been promoted to totally clarify physics of the Fast Ignition and to design targets for FIREX (Fast Ignition Realization EXperiment) project at Osaka University by the Fast Ignition Integrated Interconnecting code simulation under the tight collaborations with Osaka University, Setsunan University, Kyushu University, and the Japan Atomic Energy Agency. Under this project, the statistical collision model based on modified Langevin equation is developed for electron-electron collisions to reduce their computation time and investigate collisional effects on fast electron generation and transport in fast ignition. One-dimensional PIC simulation with the developed statistical collision model shows that, in a collisional case, the density profile steepening at the laser front is enhanced, and then the low energy component (<8 MeV) of fast electrons is generated much less than that of a collisionless case.

The Plasma Complexity Simulation Project aims to investigate magnetic reconnection phenomena, which are controlled by various physics from micro to macro-scale, in solar and magnetosphere plasma and fusion plasma, and to clarify the physics of plasma-material interaction in compound physics system. Innovative simulation methods called multi-hierarchy, multi-scale, and multi-physics models are now being developed under domestic and international collaborations. MHD-PIC interlocked simulation model is developed based on the domain decomposition method and applied to collisionless driven reconnection as a typical cross-hierarchy phenomenon. Generation mechanism of anomalous resistivity due to plasma instabilities in ion-scale current sheet is investigated by means of two-dimensional PIC simulation. Kinetic feature of blob dynamics in scrape-off layer (SOL) of magnetic confinement fusion devices is studied by using a three dimensional PIC simulation code with particle absorbing boundaries. Molecular dynamic (MD) simulations reveal the erosion and coating process by hydrogen injection on diamond surfaces, as well as the mechanism of CH_4 generation in chemical sputtering on graphitic divertor plates.

The roles of the Rokkasho Research Center of NIFS are to collaborate, in the cooperation among the activities of International Fusion Energy Research Center (IFERC) at Rokkasho village, NIFS and universities at various aspects like the start up of Computer Simulation Center (CSC) intended to operate the super computer in the early days of 2012, and to promote the cooperation.

DSS will further promote a large-scale simulation research which will lead to the construction of the helical numerical test reactor predicting overall behaviors of fusion plasmas, while assembling simulation methodologies developed in various applications into our simulation models and improving them under intensive international and domestic collaborations. In order to make these collaboration researches more effective the hardware and software simulation environment should be improved furthermore.

Two large-scale computer systems, the Plasma Simulator and the LHD numerical Analysis System, have been installed and periodically upgraded to support various research activities under the NIFS collaboration program. The Plasma Simulator is a high-performance computer system to support the studies in confinement physics of fusion plasmas and their theoretical systematization, the exploration of science of complexity as the basic research, and other collaborative researches to advance and establish simulation science. The present Plasma Simulator, HITACHI SR16000, has the total peak performance 77TFlops and the total main memory 16TB, and it will be upgraded to total peak performance 315TFlops and total main memory 32TB with 2.0PB storage in October 2012. The LHD numerical Analysis System serves mainly for the LHD Experiment Project and its related simulation projects, and the research collaboration with worldwide universities and institutes.

The computer working group has continuously worked to support various collaboration research activities with utilizing the large-scale computer systems under the NIFS collaboration programs. A large-scale numerical simulation creates a huge amount of numerical data. In order to analyze such a huge data and extract the physical essences we need to develop innovative analysis tools as a task of simulation science. The Virtual Reality (VR) taskforce has continuously developed scientific visualization technologies such as VFIVE and AVS for CAVE, which work on NIFS VR System "CompleXcope", as powerful tools to explore the science of complexity in plasma.

The social events and other academic activities including the simulation science symposium, the Toki lectures on simulation science, and various workshops were hosted to provide the opportunity for scientists to exchange opinions and academic information on simulation science and for students to lean simulation science.

We hope that the Department of Simulation Science will promote the collaboration researches on theory and simulation more intensively and contribute toward constructing simulation science.

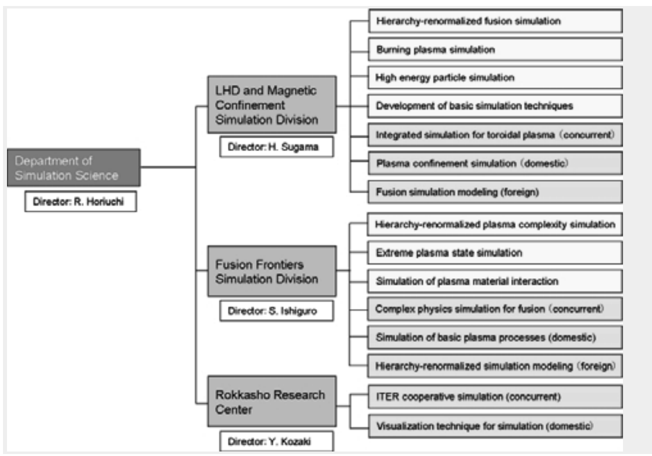

Fig.1. Organization of the Department of Simulation Science as of April 1, 2009.

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