3. Numerical Simulation Research Project

Based on the past two-decades activities at the Theory and Computer Simulation Center and the Department of Simulation Science in the National Institute for Fusion Science (NIFS), Numerical Simulation Research Project (NSRP) has been launched to continue the tasks in the theory and simulation research activities at NIFS, and evolve them in more systematic way on the occasion of the re-organization of NIFS in 2010. Under intensive international and domestic collaborations on large-scale numerical simulation, the NSRP is aiming to understand and systemize physical mechanisms in fusion plasmas and to realize ultimately the numerical test reactor (NTR) which will be an integrated predictive modeling for plasma behaviors in a whole machine range. For the realization of the NTR we need all element physics contorolling fusion plasmas which is validated by the comparison studies with experiments, and innovative numerical technologies to interlock them, together with powerful supercomputing resources at the Petascale level or more as a common platform of simulation science. And we should assemble all obtained results to upgrade integral transport model and approach the final NTR in the synergy of experimental groups and fusion engineering groups.

In order to make this approach effective, nine research groups responsible for each task in the NSRP have been set up, which cover a wide range of simulation subjects including 3D equilibrium of core plasmas and its stability, high energy particle physics, plasma heating, plasma transport, micro and macro turbulence, burning plasma physics, fueling, periphery plasmas, plasma-wall interaction, other basic plasma physics supporting fusion science, and simulation methodology such as multi-scale simulation modeling, scientific visualization. The tasks and the typical examples of their simulation results of nine research task groups are as follows.

"Plasma fluid equilibrium stability group" studies macroscopic physics of core plasmas using nonlinear MHD and extended MHD models. An MHD equilibrium including a static magnetic island has been obtained in a straight heliotron configuration using reduced MHD equations and the effect of static magnetic island on resistive interchange mode has been examined in detail. Nonlinear three-dimensional MHD simulations have been applied to the low-aspect-ratio reversed-field pinch plasma and clarified the existence of a relaxed helical state consisting of a unique bean-shaped and hollow pressure profile.

"Energetic particle group" investigates physics issues related to energetic-particles in toroidal plasmas such as Alfven eigenmodes, neoclassical transport of alpha particles in burning plasmas, and NBI/ICRF heating. Linear properties of energetic particle driven geodesic acoustic mode (EGAM) have been investigated for LHD plasmas with a hybrid simulation code for an MHD fluid interacting with energetic particles, MEGA. It is found that the EGAM frequency is in proportion to the square root of bulk plasma temperature.

"Integrated transport simulation group" works on the development of core transport code in 3D configuration (TASK3D) and its application towards prediction of the overall time evolution of observable physics quantities in the plasma core. By packing the modules, TR, DGN/LHD, FIT3D, VMEC, and BOOZER, two software environments for predictive and interactive analyses of heat transport in LHD plasmas have been established.

"Fluid turbulence transport simulation group" studies physics issues related to turbulent transport in toroidal plasmas using theory and simulation based on fluid model. Turbulence Diagnostic Simulator, which is the combination of fluid turbulence codes and numerical diagnostic modules to simulate experimental measurements of plasma turbulence, has been developed to clarify the role of turbulence structure on anomalous transport. By using a simulation code including ion and electron diamagnetism, effects of finite ion temperature on magnetic island evolution has been studied.

"Kinetic transport simulation group" aims to investigate anomalous transport mechanisms, collisional transport mechanisms and multi-scale physics of transport, and predicts the transport level for achieving efficient confinement of high-temperature plasmas based on kinetic modeling. Applying the gyrokinetic Vlasov flux-tube code GKV-X, the nonlinear ITG turbulent transport simulations has succeeded in reproducing well anomalous part of ion heat flux and poloidal wavenumber spectrum of density fluctuation observed in a LHD experiment. Collisional transport mechanisms under the influence of resonant magnetic perturbations have been studied using Delta-f Monte Carlo codes (FORTEC-3D/KEATS) to directly solve the drift kinetic equation with the finite-orbit-width effect.

"Peripheral plasma transport research group" studies impurity transport process near a plasma facing wall in LHD based on the model of boundary plasma between scrape-off layer (SOL) and divertor plate. A one-dimensional steady-state two-fluid model has been developed to study the cooling effect of gas-puffed neon on the hydrogen SOL plasma. Significant reductions of temperature and heat load onto the divertor plate have been obtained according to the neon density, which are consistent with the experimental observations.

"Plasma-wall interaction group" investigates dynamical process on the surface of plasma facing materials such as chemical spattering of divertor plate and yielding hydrocarbon, by means of molecular dynamics (MD) simulation, and its extended model. First-principles calculations of the binding energies between helium atoms and mono-vacancies of tungsten are performed with the 'OpenMX' code package, which is designed for nano-scale material simulations based on density functional theories (DFT). It is found that the binding energy gradually decreases as the number of the trapped He atoms increases, steeply drops at 7 trapped He's, and then recovers.

"Multi-hierarchy physics group" studies complex multi-hierarchy phenomena relating to fusion plasmas by developing various multi-scale or multi-hierarchy models and numerical techniques. Multi-hierarchy simulation model (MARIS) has been improved to adopt non-uniform grid spacing in the upstream direction based on the previous model and applied to collisionless driven reconnection. A potable adaptive mesh refinement (AMR) module has been developed to enable resolving the ion skin depth, the ion Larmor radius and some other scales locally in fluid and particle simulation codes.

"Simulation science basis group" aims to develop innovative analysis tools of complex simulation data such as scientific visualization on CompleXcope, and various numerical techniques for utilizing powerful supercomputing resources. Extension of VR multi-purpose visualization tool, VFIVE, has also been performed to incorporate a function for tracing the ion trajectory in a time-varying electromagnetic field. A novel and powerful visualization tool for many-particles system, "AIScope", has been developed and improved to analyze internal structure of dynamic systems.

A large-scale computer system, the Plasma Simulator has 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 40TB with 2.0PB storage in October 2012. LHD Numerical Analysis Server is used primarily for the LHD Experiment Project and its related simulation projects, and the research collaboration with the universities and the institutes. On October 14, 2011, two additional nodes, the Computation Server II and the Data Processing Server were installed in the previous system with two nodes. Each server is equipped with 32 cores of POWER7 processor (3.3GHz) and 128GB memory. The peak performance of each server is 844.8Gflops. 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.

The social events and other academic activities including the plasma simulator symposium, the Toki lectures on simulation science, symposium on hierarchy and holism in natural sciences, training course on the NIFS computer systems, and various workshops were hosted to provide the opportunity for scientists to exchange opinions and academic information on fusion simulation science and for students to lean plasma physics and fusion simulation science.

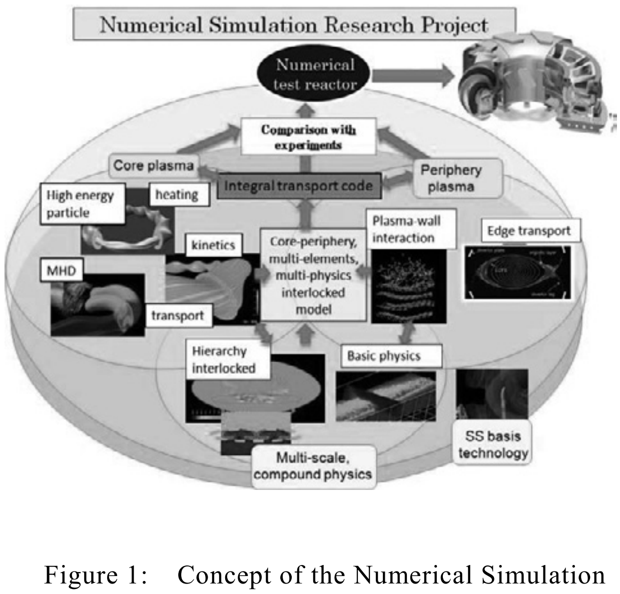

Figure 1: Concept of the Numerical Simulation Research Project.

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