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 (see figure 1). 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 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 groups are as follows.

“Plasma fluid equilibrium stability group” studies macroscopic physics of core plasmas such as MHD equilibrium, MHD stability, nonlinear global evolution of core plasma, and pellet injection using nonlinear MHD and extended MHD models. Multi-scale simulation scheme has been applied to the LHD plasma in the beta increasing phase and found the self-organization path along which the plasmas evolve towards a high-beta state without any serious disruption. Nonlinear MHD simulation clarified the saturation mechanism of moderate wave number ballooning modes which grows from a fairy unstable Rax=3.6m inwardly shifted MHD equilibrium.

“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. Comparison studies of linear and nonlinear simulation runs of a n=4 TAE evolution disclosed that the saturation level is reduced by the nonlinear MHD effects.

“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. Integrated several modules have been developed for the accurate three-dimensional physics, such as neoclassical transport coefficient, time evolution of iota (current) profile, and NBI-related physics.

“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 has been developed for understanding of turbulence structure formation mechanism based on the demonstration of experimental measurement and the correlation analysis. The turbulent transport model has been applied to the self-generated oscillation phenomena of the radial electric field in the core region of CHS and LHD.

“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. Gyrokientic simulations of the ion temperature gradient (ITG) turbulence using the GKV-X code have first successfully applied to the LHD high ion temperature discharge. Collisional transport mechanisms 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. Comparison of modeling by the EMC3 code to experimental observation on impurity screening of high density plasmas in LHD has been done. The velocity distribution function model at Debye sheath entrance has been developed to apply for impurity transport study using ERO code.

"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. Recently, hybrid simulation model for hydrogen bombardment into carbon target has been developed, i.e., atomic collisions in any structured target (AC∀T) code is employed as binary collision approximation simulation for higher energy particles than some threshold value, while its motion is simulated by the MD simulation for the lower energy particles. This hybrid simulation has first succeeded in demonstrating the hydrogen injection process into a graphite material.

"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) based on domain decomposition method has been developed and successfully applied to plasma inflow process across the micro-macro domain boundary, and collisionless driven reconnection. A sub-grid-scale effect in Hall MHD simulation in the LHD has been studied by means of full three-dimensional nonlinear simulations of pressure-driven instabilities in LHD.

Because fusion plasma as our research target is a complex system consisting of multi-scale nonlinear processes in each hierarchy and multiple physical processes, it is extremely important to establish hardware and software environment to explore such a complex system and extract underlying physics. "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. Objects created by different visualization softwares are integrally visualized in the VR space as one visualized data in the CompleXcope. As an example, integrated scientific VR visualization of the equilibrium LHD plasma in the LHD vessel device has been performed. 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 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 32TB with 2.0PB storage in October 2012. The previous LHD numerical Analysis System was replaced by the LHD numerical Analysis Server in February 2011, which consists of the computation server and the front-end server. Both of the severs are HITACHI SR16000 model XM1. Each server is equipped with 32 cores of POWER7 processor (3.3GHz) and 128GB memory. The servers are mainly utilized for the LHD Experiment Project and its related simulation projects, and the research collaboration with 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.

The social events and other academic activities including the 20-th International Toki Conference (ITC20), the simulation science symposium, the Toki lectures on simulation science, symposium on hierarchy and holism in natural science, 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.

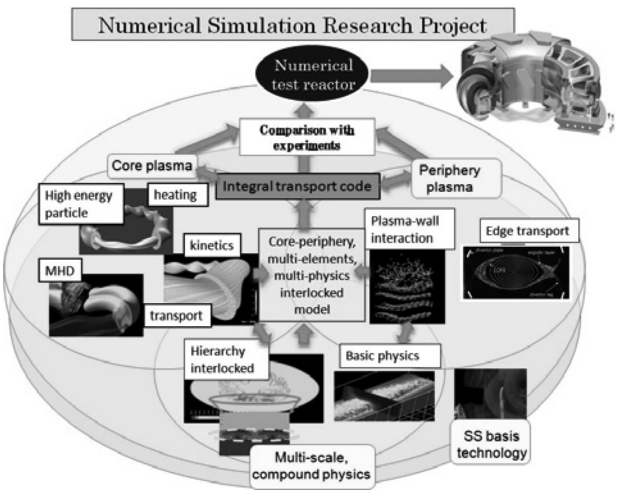

Figure 1: Concept of the Numerical Simulation Research Project.

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