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. MHD numerical simulation has been carried out to analyze a partial collapse observed in the magnetic axis swing experiments in the Large Helical Device (LHD) and revealed that the destabilization is caused by the change of the background field through the enhancement of the magnetic hill. A reduced set of MHD equilibrium equations have been analytically solved and examined for high-beta tokamaks with toroidal and poloidal flow velocities as well as with pressure anisotropy associated with parallel heat flux.

“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. The nonlinear simulations of energetic particle driven geodesic acoustic mode has been carried out with a hybrid simulation code MEGA. It is found that spontaneous frequency chirping takes place and two hole-clump pairs are formed in the energetic particle distribution function in 2-dimensional velocity space of pitch angle variable and energy.

“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. An integrated transport analysis suite, named TASK3D-a (analysis version), has been developed, which consists of 4 parts, i.e., LHD Data interface, 3D equilibrium, heating, and energy/momentum balance analysis.

“Fluid turbulence transport simulation group” studies physics issues related to turbulent transport in toroidal plasmas using theory and simulation based on fluid model. The one-dimensional transport analysis has been performed to reproduce the electric pulsation in the core region and to predict the parameter region for the electric pulsation in the LHD experimental results. Drift-interchange modes with a simplified helical plasma model have been analyzed using Turbulent Diagnostic Simulator to clarify the formation mechanism of turbulent structures.

“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. Based on nonlinear gyrokinetic simulations, a model for ion heat transport in helical plasmas has been investigated, taking account of effects of ion temperature gradient turbulence and zonal flows. Neoclassical poloidal and toroidal viscosity in torus plasmas has been evaluated based on the delta-f drift-kinetic equation solver FORTEC-3D. A multi-scale simulation model, named “flux-tube bundle” model, has been devised for turbulence and zonal flows in helical plasmas with the poloidal $E \times B$ rotation

“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. The calculation mesh of EMC3-EIRENE code has been extended to cover the divertor legs of Large Helical Device (LHD). The code is a three-dimensional fluid code to simulate parallel and perpendicular plasma transport with neutrals and calculate stational distributions self-consistently. Simulation of boundary plasmas of the LHD was launched for edge plasma without divertor legs to reduce difficulties arising in making a calculation mesh on outer region of plasma.

“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. By using binary collision approximation, density functional theory and MD, the formation mechanism of the tungsten nano-structure generated by the bombardment of helium ions has been investigated by separating into the following three processes, i.e., the penetration of helium, the diffusion and aggregation of helium, and the growth to the fuzzy nano-structure.

“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. As an extension of multi-hierarchy simulation model (MARIS), a hierarchy-interlocking method in the downstream direction has been developed and applied to plasma outflow problem from PIC domain to MHD domain. A potable adaptive mesh refinement module has been improved so that it can achieve relatively high performance in various computational environments including the Plasma Simulator in NIFS, Fujitsu FX10, Bull B510 and Cray XE5.

“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. A visualization software “Virtual LHD” has been extended to incorporate a function which draws punctures of sampled field lines on a Poincar´e section in the VR space. The data compression method “TOKI” has been proposed for particle trajectory data produced by simulation.

A large-scale computer system, the Plasma Simulator (PS) has been installed and periodically upgraded to support various research activities under the NIFS collaboration program. The PS 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 Plasma Simulator was upgraded in Phase 2 to HITACHI SR16000 model M1 on October 1, 2012. The total peak performance jumped up from 77 TFlops to 315 TFlops. The new Plasma Simulator was ranked as the 95th in the world on the TOP500 List of the high-performance computers. 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. The LHD Numerical Analysis Server (HITACHI SR16000 model XM1) consisted of four nodes. Each node is equipped with 32 cores of POWER7 processor (3.3GHz) and 128GB memory. The peak performance of each node 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 domestic and international 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.

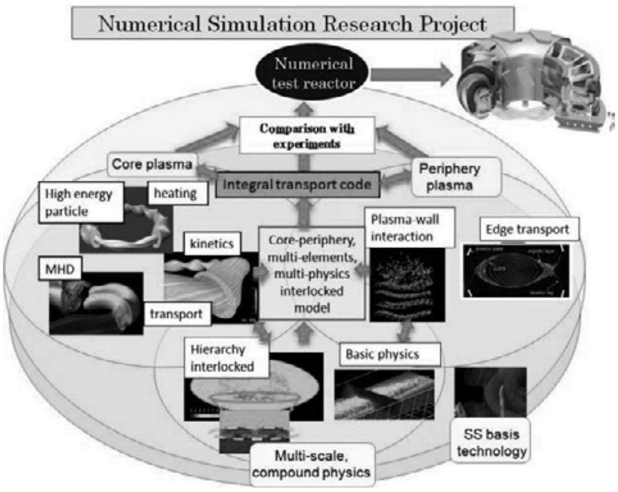

Figure 1: Concept of the Numerical Simulation Research Project.

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