学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Study on Neutronics Simulation Applicable to Various Design Requirements for Fast Spectrum Reactor

(高速炉の多様な設計要件に適用可能な核特性シミュレーションの研究)

Since the nuclear fission reaction was confirmed in 1938, human beings realized that the fission process can cause a self-sustaining chain reaction. After this point was verified through experiment, the age of nuclear power utilization started. The first commercial nuclear reactor plant *Shippingport Atomic Power Station* started to operate in 1957, and since then more than 60 years operation experience on nuclear power utilization has been accumulated. Currently, the development of nuclear reactors is in the process of moving from the third generation to the fourth generation. The majority of commercial power plant reactors are thermal-neutron reactors, i.e., using thermal neutrons (around 0.025eV) to sustain a fission chain reaction and to output energy. The utilization of uranium resources by thermal neutrons is low due to the uranium nuclear properties. Therefore, fast spectrum reactors (fast reactors in short), which can greatly improve the utilization of uranium resources, have received widespread attention and been actively promoted. Fast reactors can fully utilize uranium resources by converting fertile material into fissile material, and therefore, this process is called as *breeding*. Besides, the minor actinide (MA) from fast reactor spent fuel is considerably less than it from conventional thermal reactor. With these unique features, fast reactor technology has been being actively promoted in all major industrial countries. Currently, U.S. and Japan are promoting the *Natrium* fast reactor project, and China is constructing demonstration fast reactors *Xiapu-1* and *Xiapu-2*.

In the research field of nuclear engineering, analysis strongly relies on computer software.

The development of a new type of reactor (such as a fast reactor) begins with a conceptual design that explores a wide range of design parameter space, followed by several stages of design refinement, and eventually leads to a detailed design and plant construction. In the conceptual design stage, a large number of quick calculations are necessary for giving a solution, whereas in detailed design stage, the accuracy of solution must be ensured. Therefore, software which is capable to meet different demands at each stage of the design work would be essential.

Researches summarized in this dissertation focus on software which meets with wide range utilization in reactor design works. The first research is development and verification of a software about neutronics analysis applicable to various design stages in fast reactor development. The second research is development of a practical neutronics analysis method for intermediate stage of fast reactor design, which could be regarded as a bridge between conceptual design stage and detailed design stage.

The software used in the researches is CBZ which is a general-purpose reactor physics analysis code system, and it is independently developed at Hokkaido University. FRBurner is a fast reactor burnup calculation module that can realize various combinations on calculation methods through incorpo-

rating with various modules and solvers in CBZ. Verification of this module is conducted with an OECD/NEA fast rector benchmark. This benchmark offers four sodium cooled fast reactor concepts, which represent the general type of sodium-cooled fast reactors. Four key reactor physics parameters, effective neutron multiplication factor k_{eff}, effective delayed neutron fraction β_{eff}, sodium void reactivity $\Delta\rho_{\text{void}}$, and Doppler reactivity $\Delta\rho_{\text{Doppler}}$, are the focus and compared to reference results. Comparison with the reference results provided by other institutes indicates that the FRBurner module can provide acceptable results for general-type fast reactor physics analysis.

Secondly, comprehensive comparison between these methods is carried out for revealing the feature of each option on calculation method. This helps users choose proper methods for wide range utilization. Moreover, the computing burden is taken into account to present desirable calculation conditions for conceptual, intermediate, and detailed design stages. In addition to the solvers based on the transport and diffusion equations, a solver based on the Simplified P_3 equation (SP_3 equation) is added into CBZ. The SP_3 solver is positioned as an intermediate option between the transport and diffusion solvers. Therefore, excepts the verification part, the novelty of this research is that various methods differ from calculation theory (whole-core calculation step), dimension of lattice model (lattice calculation step), burnup chain model, and libraries four aspects are comprehensively compared in the field of fast reactors applications. It is noteworthy that a series calculation methods based on the SP_3 theory is used for fast reactor analysis in this research. Utilization of the SP_3 theory in fast reactors analysis is limited in the past. People have started to use the SP_3 theory in fast reactor analysis very recently. Therefore, the accumulated data is insufficient, and this research fills the blank from the view point of application. Building on the work of first research, the reliability of FRBurner module is well proved, and the advantage of SP_3 solver is exhibited as well. Then, an innovative reactivity calculation method is newly proposed through combining the SP_3 and perturbation theories. The equations of the SP_3-perturbation (SPP) method is derived, and verification is carried with the same OECD/NEA benchmark after the implementation is finished. Although all reactivity calculation methods based on the perturbation theory could give component-wise reactivity, the SPP method has a physical meaning unclear term in its equation. Through tracing to the theoretical source of SP_3 and defining a new form of it, the physical meaning clear term in SPP method is removed. Thus, the component-wise reactivity calculation based on the SP_3 and perturbation theories is achieved firstly in the world. Through component-wise reactivity analysis, it is demonstrated that more accurate prediction of the scattering and leakage components of reactivity can be obtained with the new method comparing to the diffusion-perturbation method.

In summary, the author has developed and verified a software applicable to meet various demands on design requirements of fast reactors, and proposed a new method (SPP method) which is useful for the reactivity analysis. These two works together contribute to the nuclear engineering field greatly.