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Overview of Recent Research Activities of Monte Carlo Simulation in Japan

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This paper describes recent progresses of the Monte Carlo simulation technology in nuclear energy field in Japan. Radiation shielding solution method using the Monte Carlo had been validated as a reliable tool through the discussion of "Radiation Shielding Safety Demonstration Analysis Group" of Japan Atomic Energy Research Institute. Since 1996, "Monte Carlo Simulation Working Group" has been accumulating use experiences of Monte Carlo codes in the wide range of nuclear energy field. This working group is planing to publish "Guideline of Monte Carlo Simulations" during FY-99. This "Guideline" is expected to be a first Japanese practical textbook of Monte Carlo calculation. In 1998, the first full-scale topical conference on Monte Carlo simulation was held in Tokyo. "Research Committee on Particle Simulation with the Monte Carlo Method" was established in Atomic Energy Society of Japan in 1998. This committee is composed of more than seventy members from many fields of nuclear energy research in Japan. This committee is expected to be a core that will drive the research and development activity of Monte Carlo calculation in Japan.

KEY WORDS: Monte Carlo, simulation, nuclear energy

I. Introduction

Time-consuming calculations of Monte Carlo have become possible with the advent of a high performance workstation or personal computer. More and more people can easily execute Monte Carlo calculation. However, most Monte Carlo calculation requires amount of knowledge and experiences to obtain appropriate solutions correctly and efficiently. The authors have been dedicated in the use and development of the Monte Carlo method before the Monte Carlo method becomes a common tool for particle transport simulation. The authors realize that an enlightenment and education of Monte Carlo technique are necessary for novices, which are increasing day by day. The authors have just launched several activities that help the Monte Carlo method prevail in the nuclear energy field of Japan. This paper reviews these activities that the authors have done for several years and also describes the future prospect of such activities.

II. Radiation Shielding Demonstration Analyses

The Science and Technology Agency of Japan entrusted the safety related issue on radiation shielding in nuclear fuel facilities to the "Radiation Shielding Safety Demonstration Board" of Japan Atomic Energy Research Institute (JAERI) in 1992. This board completed its missions in 1995. One of the objective is to demonstrate the safety margin of conventional calculation method when comparing with more accurate methods of Monte Carlo. Calculations of MCNP 4[(1)] and FSXLIB-J3[(2)] based on JENDL-3 were compared with (1) experiment of neutron deep penetration through iron at UKAEA, (2) experiment of neutron deep penetration through iron at FNS of JAERI, (3) neutron streaming experiment at ETNA facility of Italy, (4) gamma ray streaming experiment at Kansas State University and (5) neutron sky shine experiment at Yayoi reactor of University of Tokyo, (6) gamma ray sky shine experiment at Kansas State University. In the sky shine analyses, the factor of 2 or 3 overestimation was found. in the MCNP calculations. However, calculations gave conservative results. The calculation results of MCNP 4 and FSXLIB-J3 showed relatively good agreement with measurements. Through these works, it was confirmed that the Monte Carlo method can give sufficiently reliable result.

To estimate the safety margins included in a safety analyses for fuel facilities and to demonstrate the feasibility of the calculation methods, several practices for a virtual nuclear fuel reprocessing plant were analyzed by several calculation techniques. The following practices were considered: (1) glass solidification storage facility, (2) plutonium nitrate solution storage facility, (3) high level waste liquid storage facility, (4) low level waste storage facility, (5) practices for radiation streaming. In each practice, several kinds of calculation method, simplified method of discrete ordinates, detailed method of Monte Carlo, and so on were used. The inter-comparison among the results from these methods was made.

Through the above efforts, it was concluded that the safety margins of the conventional safety estimation method using

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the discrete ordinates for radiation shielding analyses were quantitatively evaluated by the comparison with the most advanced Monte Carlo method.

III. Activities of Nuclear Code Evaluation Committee

MCNP Use Experience Working Group was founded under the Nuclear Code Evaluation Committee of JAERI in 1996. The objectives of this working group were to accumulate use experiences in nuclear energy research filed with MCNP or other major Monte Carlo codes widely used in Japan. These working group members are from JAERI and other organizations. In 1996, the following subjects were discussed;[3]

(1) Compilation of point-wise cross sections for MCNP,
(2) Neutron and gamma-ray transport calculations in fusion reactor system,
(3) Concept design using MCNP of nuclear transmutation system driven accelerator,
(4) Core calculation of JMTR,
(5) Prompt neutron decay constant calculation at TCA,
(6) Subcritical measurement analyses at TCA,
(7) Neutron and gamma-ray transport calculation for exposure evaluation,
(8) Methodology of weight window generator,
(9) Analysis of ETNA neutron streaming benchmark experiment.

In 1997, variance reduction techniques of the Monte Carlo method were investigated.[4] In addition to the above subjects, Ref. (4) includes

(1) Neutron and gamma-ray calculation by MCNP for Hiroshima-type atomic bomb,
(2) Neutron streaming problem in rectangular bent duct experiment conducted at OKTAVIAN of Osaka University,
(3) Verification of perturbation calculation of MCNP 4B,
(4) Current status of high energy nucleon-meson transport code,
(5) Outline of electromagnetic cascade Monte Carlo Code EGS4,
(6) Use experience of FLUKA.

In this report, high-energy charged particle transport problems were newly included. This working group started an activity to publish "Guideline of Monte Carlo Calculation". Since no practical textbook of Monte Carlo calculation has been published thus far, this "Guideline" is expected to be a standard or a textbook of Monte Carlo calculation in Japan. The content of the "Guideline" is shown below.

Title "Guideline of Monte Carlo Calculation, Neutron & Photon Transport Simulation by Monte Carlo Method"

Preface: Theory of Simulation
1. Introduction –Chronological progress of Monte Carlo Method
2. Solving Boltzmann transport equation by Monte Carlo method –Development of basic theory
3. Variance reduction technique –Examples of MCNP and MVP[5]
4. Neutron/Photon cross section library –Examples of MCNP and MVP
5. Validation criterion of calculated value
6. Examples of Monte Carlo calculations –Detailed input data and application of variance reduction
   - 6-1 Fusion reactor
   - 6-2 Design of ITER
   - 6-3 Nuclear transmutation system
   - 6-4 Core design
   - 6-5 HTTR of JAERI
   - 6-6 Burnup calculation (MCNP-BURN)
   - 6-7 Criticality safety
   - 6-8 Radiation shielding 1
   - 6-9 Radiation shielding 2
   - 6-10 Nuclear fuel facility
   - 6-11 Health physics
   - 6-12 Radiation exposure of atomic bomb
7. Noise analysis by Monte Carlo method –Example of MCNP-DSP
8. Function enhancement program –Examples of MCNP and MVP
9. Future problems
10. Parallel calculation
11. Conclusions

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This "Guideline" will be completed and published during FY-99.

Function Enhancement working group was founded in order to expand the capabilities of existing Monte Carlo calculation code. This working group discussed the following subjects.

(1) Addition of capability to MCNP for reactor noise analysis
(2) Introduction of Next Event Surface Crossing Estimator to MCNP. This is an estimator in which the concept of the point detector is applied to the surface crossing estimator.
(3) Development of a new tally capability that discriminates the collide nuclides.

"Parallel Monte Carlo Calculation" working group dealt with parallel processing of Monte Carlo codes for neutron, photon and electron transport problems. The working group conducted parallel processing of MCNP[6]. It was concluded that it is difficult to attain high performance by static load balancing in especially neutron transport problems. A dynamic load balancing method was developed so that the sum of the computational and communication costs can be minimized by changing the number of assigned particles. This dynamic load balancing method overcomes the difficulties involving in Monte Carlo parallel calculation and it achieved nearly fifteen percentage of reduction for execution time.

"MCNP High Temperature Library Production" Working Group started in 1998. Conventional point-wise library had

been limited for room temperature only and continuous energy Monte Carlo code had not been available for power reactor analysis. To produce a point-wise cross section library more efficiently, an automatic editing system for MCNP library, autonj (automatic NJOY) was developed. Based on JENDL-3.2, a cross section library including 340 nuclides was created for 293, 600, 900, 1200, 1500, 2000K. This library corresponds to MCNP 4B. This library and autonj will be released through RIST (Research Organization for Information Science & Technology). After MCNP 4C is released, possibly, in summer of 1999, autonj will soon be revised so that it can handle the probability tables to represent unresolved resonances. This working group is planing to create a point-wise cross section library based on JENDL-3.3 after it is released.

IV. First Symposium on Monte Carlo Simulation

Nuclear Code Evaluation Committee of JAERI held a symposium[7] on Monte Carlo simulation on September 10 and 11, 1998 in Tokyo. This symposium was the first full-scale one on Monte Carlo simulation that has ever been held in Japan. There were 106 participants and 21 oral presentations were made. The extensive topics on Monte Carlo simulation were presented and intensive discussions were made by the participants. The topics were, general issue of Monte Carlo method, reactor physics, core design, burnup calculation, criticality safety, radiation shielding, health physics, transmutation, fusion plasma, fusion reactor design, electromagnetic cascade and parallel calculation. This symposium expressed that Monte Carlo method is now not only a calculation tool for benchmark problem, but also a tool for large-scale realistic facilities. This symposium will be expanded to a nationwide conference in the near future, which will hopefully be a good opportunity of information exchange.

V. Research Committee on Particle Simulation with Monte Carlo Method

In order to gather more members and their knowledge and experiences, "Research Committee on Particle Simulation with Monte Carlo Method" was established in the Atomic Energy Society of Japan in October 1998, which inherits the roles of MCNP Use Experience Working Group. Approximately 60 members were selected from universities, research institutes and industries. The meeting of this committee will be held quarterly until September 2000. This committee will deal with many aspects of nuclear energy research such as radiation shielding, criticality safety, core analysis, high-energy radiation science, nuclear medicine, accelerator and space development, etc. Regarding these subjects, this committee's agenda is as follows; (1) comparison between Monte Carlo and deterministic methods, (2) investigation of efficient variance reduction techniques, (3) publication of benchmark problems and their recommended answers, (4) search for newly applicable fields of Monte Carlo methods in nuclear energy. To do the tasks of agenda (3) efficiently, five working groups were established under the committee; (1) radiation shielding, (2) criticality safety, (3) core analysis, (4) high-energy radiation, (5) medicine, accelerator, space development.

This committee is expected to be a core that will drive the research and development activity of Monte Carlo calculation in Japan.

VI. Conclusion

As explained above, distinguished progress of Monte Carlo simulation technique in nuclear research field have been achieved during the latest decade. As a concluding remark, future subjects we are going to resolve are presented as follows.

(1) Development of versatile automatic variance reduction method
(2) Error estimation of Monte Carlo burnup calculation
(3) Development of perturbation capability
(4) Estimation of reliability of Monte Carlo calculation
(5) Development of quasi-random number for extremely large history calculation
(6) Development of user-friendly three-dimensional input interface
(7) Speed-up of Monte Carlo calculation
(8) Development of automatic dynamic load balancing for parallel calculation

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