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Present Status of Monte Carlo Seminar for Sub-criticality Safety Analysis in Japan

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This paper provides overview of the methods and results of a series of sub-criticality safety analysis seminars for nuclear fuel cycle facility with the Monte Carlo method held in Japan from July 2000 to July 2003. In these seminars, MCNP-4C2 system (MS-DOS version) was installed in note-type personal computers for participants. Fundamental theory of reactor physics and Monte Carlo simulation as well as the contents of the MCNP manual were lectured. Effective neutron multiplication factors and neutron spectra were calculated for some examples such as JCO deposit tank, JNC uranium solution storage tank, JNC plutonium solution storage tank and JAERI TCA core. Management for safety of nuclear fuel cycle facilities was discussed in order to prevent criticality accidents in some of the seminars.

KEYWORDS: Monte Carlo, seminar, sub-criticality, nuclear fuel cycle facility, MCNP-4C2, personal computer, JCO deposit tank, JNC uranium solution storage tank, JNC plutonium solution storage tank, JAERI TCA core

1. Introduction

To promote the radiation transport calculation with the Monte Carlo method in the field of the nuclear energy research, Monte Carlo seminars[1)] have been held since July 2000 at the Japan Atomic Energy Research Institute (JAERI). They are (1) fundamental theory seminars, (2) sub-criticality safety analysis seminars for nuclear fuel cycle facilities, (3) shielding safety analysis seminars, (4) neutron and photon streaming safety analysis seminars and (5) high energy shielding safety analysis seminars. In each seminar, the maximum number of participants is limited to five aiming at man-to-man discussion, and the total lecture time is six hours. Participants to these seminars are engineers and researchers from universities, research institutes and enterprises.

This paper provides overview of the methods and results of a series of sub-criticality safety analysis seminars for nuclear fuel cycle facility with the Monte Carlo method held from July 2001 to July 2003.

The objective of these seminars was a presentation of a reliable analysis method with the Monte Carlo method for beginners by using note-type personal computers (PCs).

As a continuous energy Monte Carlo code, the MCNP-4C2[2)] MS-DOS version was used.

Since the JCO criticality accident occurred in 30 Sept. 1999 at Tokai-mura in Japan, management for safety of nuclear fuel cycle facilities was discussed among the lecturer and participants in the seminars in order to prevent criticality accident.

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2. Provision prior to Monte Carlo simulation

2.1 Basic theory for the Monte Carlo calculation

Before starting the Monte Carlo calculation, following contents were lectured as a basic theory ; (1) continuous energy Monte Carlo codes, (2) nuclear data files, (3) point-wise neutron cross section compilation systems, (4) multi-purpose point-wise neutron cross section libraries, (5) Monte Carlo simulation method, (6) evaluation for calculation results, (7) forward and adjoint integral emergent particle density equations, (8) pseudorandom number, (9) random walk, (10) variance reduction technique, (11) weight window method, (12) weight window generator, (13) estimators, (14) MCNP-4C input manual, (15) calculation exsamples in the research field of criticality, shielding, reactor, exposure, fusion, high energy and space.

2.2 Installation of MCNP-4C2 system in each PC

The dominant factor limiting the utilization of the Monte Carlo codes is complex installation procedure. To solve this problem, the following simple installation method was prepared for these seminars:

The MCNP-4C2 MS-DOS version system was installed to each PC by using an auto-installer for the WINDOW'S-95,-98,-ME,-2000 and –XP.

The system consists of (1) compiled MCNP-4C2 program, (2) cross section directory, (3) 340 nuclei neutron cross section library edited from JENDL-3.2 at 293K (≤20MeV), (4) thermal neutron scattering table $S(\alpha, \beta)$[2)], (5) photon interaction cross section library (1keV-100GeV)[2)], (6) electron interaction cross section library (10keV-100GeV)[2)], (7) MCNP sample inputs.

Data of (2) and (7) are card image, but other data are binary. As a result, the installed total memory size is below 280Mbytes. This size is not large on present PCs. Speeds of the used PC were from 150MHz to 2.3GHz. This speed is enough for sub-criticality safety analysis.

3. Sample calculation of k_{eff} and neutron spectrum

3.1 Sphere model

As a first step, the most simple calculation model suitable for Monte Carlo beginners was provied. It is a *sphere* with uranium and hydrogen mixture located at coordinate XYZ origin. The radius is R cm. The density of the mixture is 18.7g/cm^3. The atomic fraction is 0.1 for hydrogen , 0.1 for uranium-235 and 0.8 for uranium-238.

The point source with Watt-type neutron spectrum[2) was set at coordinate XYZ origin. The neutron importance is 1 and −1 for the inside and outside of the sphere, respectively. The $S(\alpha,\beta)$ of light water with 300K[2) was used. The neutron number per cycle is 1000 and the total cycle number is 110. But, 10 cycles were skipped for the eigenvalue calculation (effective neutron multiplication factor k_{eff}) .with the covariance-weighted combined estimator[2) that consisted of collision estimator[2), absorption estimator[2) and track-length estimator(TLE)[2).

Then, the critical radius R_c was calculated, and the average neutron spectrum $\Phi_{ave}(E)$ of the inside of the sphere was also calculated with the TLE.

There were calculated with the different atomic fraction of hydrogen, and the each Φ_{ave} (E) was compared with Watt-type neutron spectrum.

The R_c and $\Phi_{ave}(E)$ were also calculated on condition with beryllium reflector of thickness 5cm. Then, $S(\alpha,\beta)$ of beryllium metal with 300K[2) was also used.

3.2 JCO deposit tank

The JCO deposit tank was modeled by SUS304L *cylinder* geometry with outer radius 25cm, height 50cm and wall thickness 2.5mm

The volume source with Watt-type neutron spectrum[2) was set in uranium solution. The neutron importance is 1 and −1 for the inside and outside of the tank, respectively. The $S(\alpha,\beta)$ of light water with 300K[2) was used. The neutron number per cycle is 1000 and the total cycle number is 110. But, 10 cycles are skipped for the k_{eff}.

As well as the above sphere model, the k_{eff} was calculated, and the $\Phi_{ave}(E)$ in the uranium solution and tank wall was also calculated with TLE. There were calculated on the condition with different solution surface levels from zero to critical solution level.

As a final step, water jacket was modeled for strict calculation.

When the uranium solution with critical condition was put in SUS304L cylinder tank with outer radius 12.5cm, height 150cm and thickness 2.5mm, the k_{eff} was calculated. It is about 0.80, because the neutron leakage is increased on the model. This is a general idea of geometry management for sub-criticality in nuclear fuel cycle facility. In these seminars, the condition for sub-criticality was considered in detail.

3.3 JNC uranium solution storage tank

The uranium solution storage tank at JNC Tokai reprocessing plant was modeled by SUS304L *cylinder* geometry with outer radius 115cm, height 120cm and wall thickness 5mm. The calculation condition is same as the JCO deposit tank. The k_{eff} and $\Phi_{ave}(E)$ were calculated with solution surface levels from zero to 120cm. As a final step, when the tank was immersed for conservative evaluation, the k_{eff} was calculated.

For all calculation conditions, the k_{eff} is below 0.61.

3.4 JNC plutonium solution storage tank

The plutonium solution storage tank at JNC Tokai reprocessing plant was modeled by SUS304 *hollow circle ring* cylinder geometry with the first wall outer radius 245.5cm, the second wall outer radius 235cm, height 240cm and wall thickness 5mm. The outside of No.2 wall is covered with cadmium plate with thickness 1mm. The calculation condition is same as the JCO deposit tank except for the parameter[2) of Watt-type neutron spectrum. The k_{eff} and $\Phi_{ave}(E)$ were calculated with solution surface levels from zero to 240cm. As a final step, when the tank was immersed for conservative evaluation, the k_{eff} was calculated.

For all calculation conditions, the k_{eff} is below 0.82.

3.5 JAERI TCA benchmark experiment core

JAERI TCA is a light water critical assembly with light water fuel rod array[4). Fuel rod pitch is 1.956cm. In this seminar, the information of *18×18 square array* core was used. The MCNP input is not here, because of very complex description. It is shown in Ref.5. The volume source with Watt-type neutron spectrum was set in all fuel pellets. The critical water level is 75.0cm. The k_{eff} were calculated with water levels from zero to 75.0cm. The $\Phi_{ave}(E)$ in the pellet, cladding and water were also calculated at the different core positions.

4. Discussion

4.1Discussion on credibility of Monte Carlo cal.

Recently, PCs have been used in many scientific fields. The WINDOW'S is an excellent operation software. PCs with the WINDOW'S are suitable for the Monte Carlo calculation because of simple operation by using the WINDOW'S, high speed (2GHz) and large memory capacity(10Gbytes). If installation of MCNP system is simple and easy by use of an auto-installer and CD package, the Monte Carlo method come into wide use in nuclear energy research. For the seminars, one-touch installation method within one minute is prepared by using simple program, CD package and an auto-installer for WINDOW'S-95, -98, -ME, -2000, -XP.

The CPU time is shorter than five minutes with 100,000 histories for the sphere model, the JOC deposit tank, the JNC uranium solution storage tank and the JNC plutonium solution storage tank, and about 30 minutes for JAERI TCA. Benchmark experiment core.

The $k_{eff} \pm \Delta k_{eff}$ of the JAERI TCA benchmark experiment core with a critical condition is 1.00238 ± 0.00088 by using the pointwise neutron cross section library edited from JENDL-3.2. The accuracy and precision are acceptable enough.

For JAERI TCA cores, sub-criticality evaluated with the exponential experiment and the Monte Carlo calculation was compared for range from 0.63 to just under criticality[6]. The C/E's are 0.985 for sub-criticality 0.63 and1.004 for just under criticality.

However, for the uranium solution and the plutonium solution, deep sub-criticality data from 0.65 to 0.90 with the some experimental method did not exist. Therefore, the accuracy evaluation method of the deep sub-criticality with the Monte Carlo method for the JCO deposit tank, JNC uranium solution storage tank and the JNC plutonium solution storage tank is not established in the world yet. But, the realistic estimation is possible on comparison with the JAERI TCA results[6].

For this reason, the result of the Monte Carlo calculation is reliable. The Monte Carlo Method is applicable with high reliability to sub-criticality safety analysis of nuclear fuel cycle facility.

4.2 Discussion to prevent criticality accidents

The criticality accident occurs by many factors. Representative factors are the ethics of the management policy, the ethics of the employees, the engineering ability of engineers and the knowledge and attention of workers in the plant. Engineers and workers of the enterprise will not do to mistake such as the estimation of the sub-criticality at least, if they are able to carry out freely the Monte Carlo calculation with the note-type PC. We believe that it was able to prevent the JCO criticality accident, if these seminars were carried out for the persons concerned of the nuclear fuel cycle facilities from before of the JCO criticality accident.

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