Monte Carlo Nuclear Data Uncertainty Analysis for VENUS-1 criticality

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1. Introduction

The k_{eff} or power distribution estimated by Monte Carlo (MC) method is unavoidably associated with the uncertainties because of the uncertainties of the nuclear cross section data and the its stochastic nature. The statistical uncertainties could be easily controlled by the total number of neutron histories employed in MC runs. On the other hand, there have been various studies to examine quantitatively the effect of the uncertainties of nuclear cross sections.

Recently, we presented a new MC formulation[1] for analyzing the uncertainty propagation in MC depletion calculations and the effect of cross section uncertainties on analysis of criticality benchmark problems. In this paper, the MC uncertainty analysis for VENUS-1 experiments[2] is performed to quantifying the effect of nuclear design parameters such as an effective multiplication factor and reaction rates using the sensitivity and uncertainty(S/U) analysis module of McCARD[3] and the available covariance data.

2. VENUS critical facility

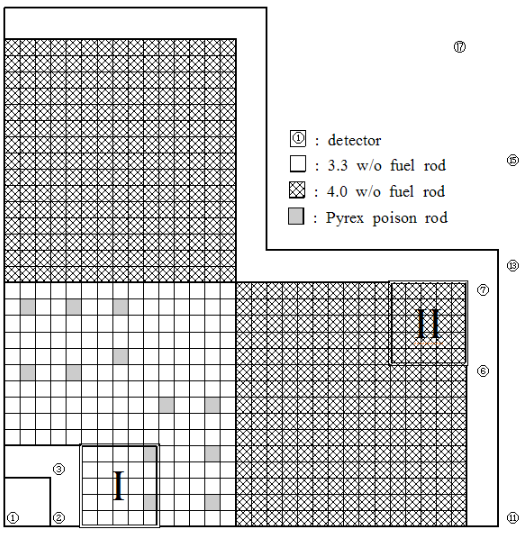

Fig. 1. Configuration of VENUS

Figure 1 shows the configuration of VENUS core. The central hole is filled with the water, surrounded by a 2.858-cm thick inner steel baffle. The core is made of twelve "15x15" subassemblies with the 1.26cm pin-to-pin pitch equal to that of the 17x17 PWR assembly. The four inner cores contain 752 zircaloy-clad 3.3 w/o enriched UO_2 fuel rods with 48 pyrex burnable poison rods while the outer core contain 1800 steel-clad 4.0 w/o enriched UO_2 fuel rods. The core is surrounded by a 2.858 cm thick outer steel baffle, a water reflector, barrel, water-gap, a neutron pad, and the reactor pool. The detectors for VENUS-1 are loaded in several locations from core to neutron pad as shown in Fig 1. The reaction rates are calculated using the neutron flux at each detector.

3. Numerical results

All the McCARD Calculations were performed employing 10,000 neutron histories per a cycle, 10,000 active cycles, and 50 inactive cycles based on JENDL-3.3 nuclear data library. To confirm the dependency of MC calculations on evaluated nuclear data library, the McCARD calculations are performed using ENDF/B-VI, and ENDF/B-VII.

3.1 k-effective

Table I shows McCARD estimates of k_{eff} for VENUS-1 experiments using three different nuclear data library; JENDL-3.3, ENDF/B-VI, and ENDF/B-VII. The k-effective of the ENDF/B-VII case differs from ENDF/B-VI.8 by 549 pcm while that of the JENDL-3.3 case differ by 334 pcm.

Table II and Figure 2 shows the uncertainty of k_{eff} by the cross section type and nuclide. The total uncertainty of k_{eff} due to the uncertainty of cross section library, $\sigma_{xx}(k_{eff})$, is estimated to 360 pcm while the statistical uncertainty $\sigma_s(k_{eff})$ is about 7 pcm. It is observed that the uncertainties of the U^{235} ν(nue), the U^{238} capture cross section, and the U^{238} inelastic cross section turned out to contribute most to $\sigma_{xx}(k_{eff})$.

Table I: k-effective of VENUS-1

Case	k-effective
ENDF/B-VI.8	0.99784±0.00007
ENDF/B-VII	1.00333±0.00007
JENDL-3.3	1.00118±0.00007

3.2 Reaction rate

Table III show the C/E values of the ^{238}U fission reaction rates in the seven detectors, which are located at central hole, inner baffle, outer baffle, and barrel. All results are normalized to the maximum value. Table IV show the uncertainty of ^{238}U fission reaction rates in the seven detectors. Overall, it is observed that the uncertainty by the nuclear cross section is dominant.

Table II: Contribution of cross section uncertainties of U isotope to $\sigma_{xx}(k_{eff})$ of k_{eff} for VENUS-1

Reaction Type		Covariance between reaction types	
α	α'	U^{235}	U^{238}
ν	ν	7.27×10^{-6}	1.60×10^{-5}
(n,γ)	(n,γ)	1.49×10^{-9}	3.51×10^{-6}
(n,f)	(n,f)	7.02×10^{-10}	2.14×10^{-8}
(n,n)	(n,n)	2.86×10^{-11}	3.97×10^{-8}
(n,n')	(n,n')	817×10^{-9}	1.63×10^{-6}
(n,n)	(n,n')	-4.48×10^{-10}	-2.19×10^{-7}
(n,γ)	(n,n)	1.00×10^{-11}	5.11×10^{-8}
(n,f)	(n,n)	-3.50×10^{-12}	-1.46×10^{-10}
k_{eff}		1.00118	
$\sigma_{xx}(k_{eff})$		0.00360	

Table III: C/E values for ^{238}U fission reaction rates in 7 detectors

Case	C/E values of ^{238}U fission reaction rates		
	ENDF/B-VI.8	ENDF/B-VII	JENDL-3.3
Detector 1	0.969	1.032	0.959
Detector 2	0.995	1.005	0.994
Detector 3	1.000	1.000	1.000
Detector 6	0.991	1.010	1.001
Detector 11	0.992	1.008	1.019
Detector 13	0.968	1.033	0.976
Detector 17	1.002	0.998	1.010

Table IV: Uncertainty of ^{238}U fission reaction rates in 7 detectors

Case	Uncertainty of ^{238}U fission reaction rate (%)		
	σ	σ_s	σ_{xx}
Detector 1	1.71	1.14×10^{-4}	1.71
Detector 2	1.72	1.13×10^{-5}	1.72
Detector 3	1.75	5.71×10^{-6}	1.75
Detector 6	2.07	1.17×10^{-5}	2.07
Detector 11	2.33	1.65×10^{-5}	2.33
Detector 13	2.53	6.47×10^{-5}	2.53
Detector 17	2.15	5.62×10^{-5}	2.15

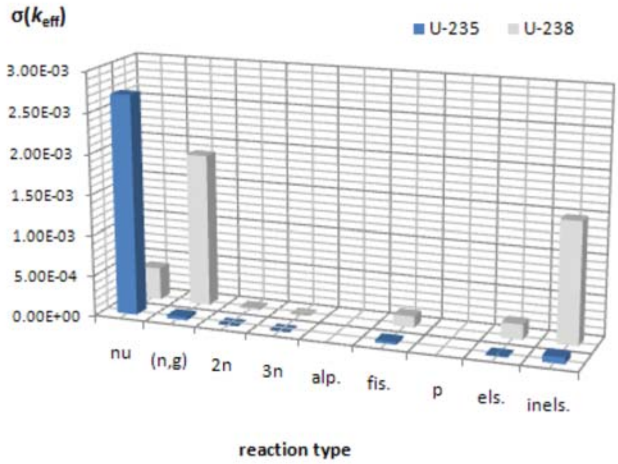

Fig. 2. Contribution of nuclear data uncertainties to $\sigma(k_{eff})$ by cross section type and nuclide for VENUS-1

4. Conclusions

In this study, the nuclear data uncertainty analysis for VENUS-1 experiments is performed by the McCARD S/U analysis module. From these results, we can see the effect of cross section uncertainties on k_{eff} and reaction rates and the performance of the new MC formulation.

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