Nuclear Data for Design of Reduced Moderation Light Water Reactor

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Reduced Moderation Water Reactor (RMWR) is a MOX fueled light water reactor (LWR) which can realize a higher conversion ratio than 1.0 by reducing moderator to fuel ratio than the current LWR. Neutronically, the reactor has intermediate neutron spectrum between conventional LWR and fast reactor (FR). To study the effect of nuclear data uncertainty on the physics behavior of RMWR, by using a simple benchmark calculation model, reactor physics characteristics were estimated with the different nuclear data libraries JENDL-3.3, ENDF/B-VI.8 and JEFF-3.0. As a result, for the precise estimation of the important integral parameters such as multiplication factor, void reactivity and conversion ratio, the nuclear data in all fast, resonance and thermal energy regions are found to be important. The most important difference in multiplication factor and void reactivity between ENDF/B-VI.8 and JENDL-3.3 was shown to be caused from the difference in the fast neutron spectrum mainly due to the difference in ^{238}U inelastic scattering cross section.

1. Introduction

For the efficient utilization of uranium resources based on the well experienced light water reactor (LWR) technology, Reduced Moderation Water Reactor (RMWR) concept has been studied in Japan Atomic Energy Agency (JAEA). In RMWR, it is possible to achieve the conversion ratio of higher than 1.0 and to keep the quality of plutonium (ratio of fissile to total plutonium) after burnup. The reactor can therefore sustainably supply energy for a long term through plutonium multiple recycling.

The current RMWR design is a boiling water reactor (BWR) type, and a high conversion ratio is realized by reducing the moderator to fuel ratio with a triangular tight pitched fuel lattice and a higher core averaged moderator void fraction than the existing BWR. In Fig. 1 are compared the neutron spectra in the current standard axially heterogeneous RMWR core with those in LWR and fast reactor (FR). In both upper and lower core regions in RMWR with different moderator void fraction, the neutron spectrum is intermediate between conventional LWR and FR as shown in this figure, and the neutronic characteristics of RMWR are different both from current LWR and FR. To study the effect of nuclear data uncertainty on the reactor physics characteristics of RMWR, by using a 1-dimensional simplified benchmark calculation model on the axially heterogeneous RMWR core, reactor physics characteristics such as multiplication factor, void reactivity and conversion ratio were estimated with the different nuclear data libraries JENDL-3.3, ENDF/B-VI.8 and JEFF-3.0.

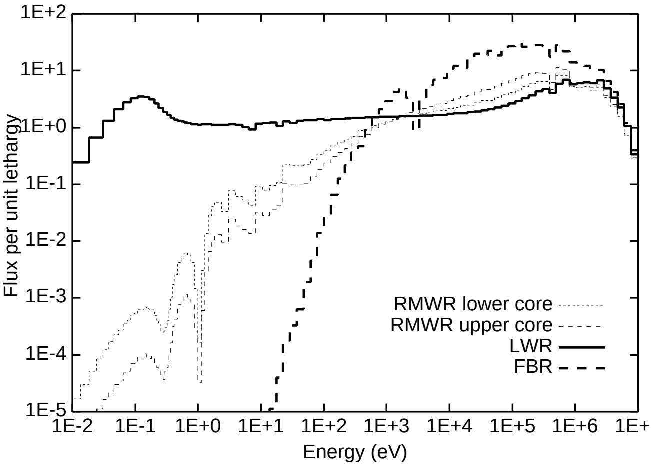

Fig. 1 Neutron spectrum in LWR, RMWR and FR.

2. Calculation model and method

One-dimensional slab geometry benchmark calculation model is considered based on the current standard axially heterogeneous RMWR design. The model consists of two MOX fueled core regions of 23cm height and 18 wt.% fissile Pu, 20cm height upper and lower blanket and 40 cm height inner blanket regions with depleted UO_2 and upper and lower reflector regions. moderator void fraction increases from 0% in lower reflector region to 85% in upper blanket and reflector regions.

Cross sections in the core and the blanket regions are to be obtained by the cell calculations on a cylindrical pin cell model. The cell model is consisted of the fuel pin of the pin diameter of 13mm with the zircaloy cladding of 0.83mm thickness surrounded by the H_2O coolant region of the cell diameter of 15.016mm. This cylindrical cell diameter corresponds to the fuel pin pitch of 14.3mm in hexagonal pin cell.

The cell calculations were performed with the collision probability method by using the SRAC95 code system [1], and the 1-D core calculation based on the diffusion method also by using the SRAC95 and COREBN95 [1] system.

3. Integral parameters of RMWR core

3.1 Effective multiplication factor

Effective multiplication factors of 1-dimensional axially heterogeneous RMWR core model calculated with nuclear data libraries ENDF/B-VI.8 and JEFF-3.0 as a difference from JENDL-3.3 are compared in Fig. 2. As shown in this figure, ENDF/B-VI.8 was found to give ~1.5% larger multiplication factor than JENDL-3.3 and JEFF-3.0. This difference corresponds to, in terms of burnup period, about 500days or >5GWd/t. This is a very big difference from the viewpoint of reactor core design to precisely estimate the discharge burnup of RMWR.

3.2 Void reactivity

Moderator void reactivities were estimated both for the 5% void fraction increase from the nominal condition, and for the void change from nominal to 100% void. In both cases, more positive side void reactivities were obtained with ENDF/B-VI.8 data library than the other libraries.

For the 100% void case, void reactivity difference from the JENDL-3.3 result is shown in Fig. 3, and the difference between ENDF/B-VI.8 and the other libraries corresponds to about 1.5×10^{-4}dk/k in terms of void reactivity coefficient. Almost the same difference in void coefficient is also observed in the +5% void case. The prediction of void coefficient, if it is to be negative or not, is very important in RMWR design study. As the negative void coefficient of current standard RMWR design is in the order of 10^{-4}dk/k, above shown difference between nuclear data libraries is also very large.

3.3 Conversion ratio

In contrast with the multiplication factor and void reactivity cases, the difference in conversion ratio between the results with different nuclear data libraries is not so large. It was found ENDF-B-VI.8 gives 0.5% larger conversion ratio at the beginning of burnup life (BOL) and 0.5% smaller at the end of burnup life (EOL) than JENDL-3.3 and JEFF-3.0.

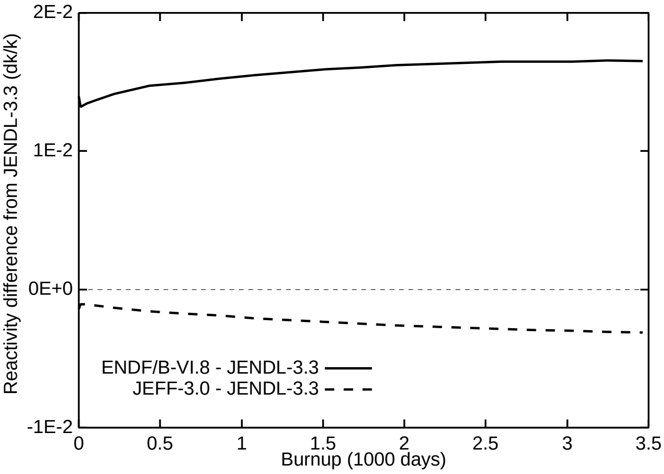

Fig. 2 Calculated multiplication factor difference from JENDL-3.3 of 1-d axially heterogeneous RMWR core model.

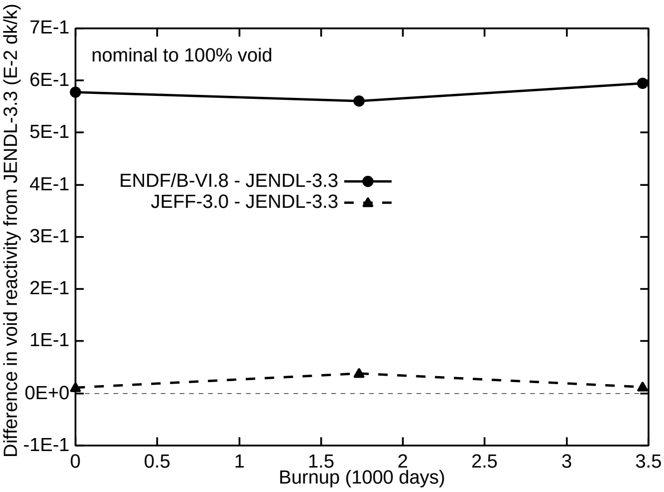

Fig. 3 Void reactivity difference from JENDL-3.3 of RMWR core calculated for nominal to 100% void fraction change.

4. Nuclide-wise and energy group-wise breakdown of the difference in integral parameters

4.1 Multiplication factor difference

To understand the cause of the difference in integral parameters estimated with different nuclear data libraries, nuclide-wise and energy group-wise contributions to the difference were next compared. Figure 4 shows the neutron production and absorption reaction rate differences between ENDF/B-VI.8 and JENDL-3.3 in the lower core region cell both at BOL and EOL. These reaction rate differences show the contribution of each nuclide to the difference in multiplication factor. This figure indicates that the most important contributions are from the production rates of ^{238}U, ^{239}Pu and ^{240}Pu both at BOL and EOL. Similar contributions were observed also in the upper core cell.

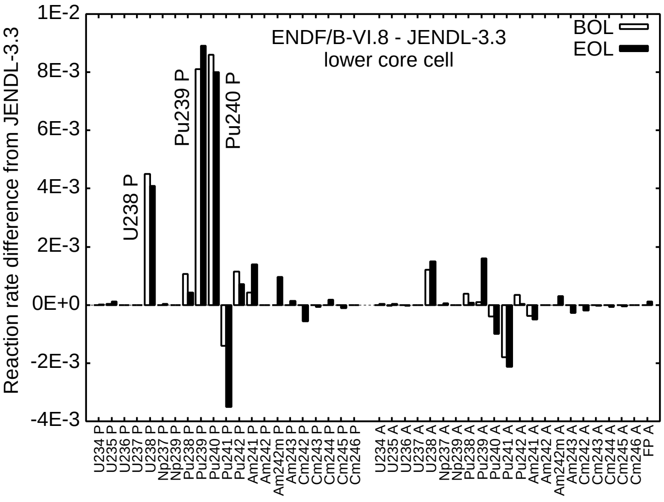

Fig. 4 Nuclide-wise contribution to the difference of multiplication factor in lower core cell calculated with ENDF/B-VI.8 from JENDL-3.3 (P : production rate, and A : absorption rate of nuclides).

From the energy group-wise comparison of the production rates of ^{238}U, ^{239}Pu and ^{240}Pu, all the contributions of these reactions to the multiplication factor difference were shown to come from the fast energy range above 10^5eV (Fig. 5). Furthermore from the comparison of the cross sections, no significant difference in fission cross sections between ENDF/B-VI.8 and JENDL-3.3 was found in the energy region of $10^5 < E < 10^7$eV, and only slight difference in ν values without such strong energy dependence as in Fig. 5. The difference in the production rates of these nuclides in the fast energy region is mainly caused from the neutron spectrum difference calculated with ENDF/B-VI.8 and JENDL-3.3, as shown in Fig. 6.

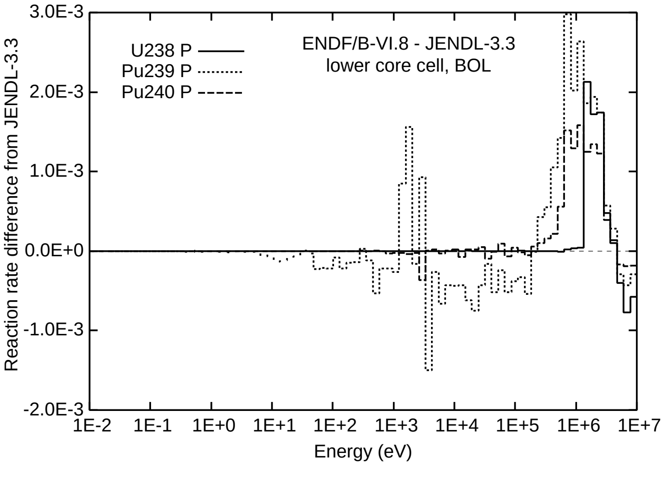

Fig. 5 Energy dependency of the difference in production rates between ENDF/B-VI.8 and JENDL-3.3.

4.2 Void reactivity difference

Similarly to the multiplication factor case, the difference between ENDF/B-VI.8 and JENDL-3.3 is mainly caused from the production rates of ^{238}U, ^{239}Pu and ^{240}Pu, due to the difference in the fast energy range of the neutron spectrum change from nominal to voided state.

4.3 Conversion ratio difference

Table 1 summarizes the conversion ratio in each region of the axially heterogeneous core calculated with ENDF/B-VI.8 and JEFF-3.0 in comparison with the JENDL-3.3 results. The conversion ratios of the whole core do not differ very much each other between the libraries, but there are found several larger differences in the region-wise conversion ratio. In the core regions, ENDF/B-VI.8 and JEFF-3.0 give smaller conversion ratio than JENDL-3.3, and the difference between ENDF/B-VI.8 and JENDL-3.3 is larger. In the blanket regions, ENDF/B-VI.8 and JEFF-3.0 both give similarly larger conversion ratio than JENDL-3.3.

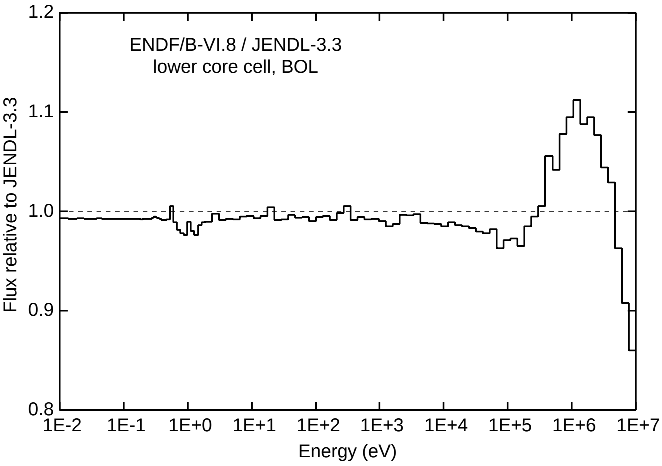

Fig. 6 Neutron spectrum in the lower core cell calculated with ENDF/B-VI.8 relative to the spectrum calculated with JENDL-3.3.

In the core regions, the difference is mainly contributed by ^{240}Pu capture rate especially in resonance energy region around E$\sim$10^{3}eV (Fig. 7). The difference is mainly due to ^{240}Pu capture cross section around 1keV. While in the blanket regions, the conversion ratios calculated with ENDF/B-VI.8 and JEFF-3.0 are larger than the JENDL-3.3 case because the absorption rate of ^{235}U is smaller than JENDL-3.3. But from the viewpoint of the ^{239}Pu production in the blanket regions, the difference in the ^{238}U capture rate between the libraries is large and important. The difference comes from all fast to thermal energy regions, particularly in the lower blanket region (Fig. 8), where the neutron spectrum is much softer than the other regions. The difference is due to both the ^{238}U capture cross section and the neutron spectrum.

Table 1 Conversion ratio in each region

region		JENDL-3.3	ENDF/B-VI.8	JEFF-3.0
whole core	BOL	1.164	(+0.5%)	(+0.0%)
	EOL	1.085	(-0.4%)	(+0.0%)
lower blanket	BOL	6.051	(+0.2%)	(+0.2%)
	EOL	1.477	(+0.3%)	(+0.1%)
lower core	BOL	0.4524	(-1.1%)	(-0.51%)
	EOL	0.6687	(-1.0%)	(-0.09%)
inner blanket	BOL	11.85	(+0.3%)	(+0.3%)
	EOL	1.610	(+0.7%)	(+0.3%)
upper core	BOL	0.4494	(-1.4%)	(-0.60%)
	EOL	0.6642	(-1.3%)	(-0.14%)
upper blanket	BOL	17.96	(+0.2%)	(+0.3%)
	EOL	1.650	(+0.8%)	(+0.4%)

( ) : difference from JENDL-3.3

5. Library effect on multiplication factor and void reactivity

The difference in multiplication factor and void reactivity between ENDF/B-VI.8 and JENDL-3.3 is very important from the RMWR core design point of view. It seems necessary to further investigate the cause of the difference, i.e., what kind of cross section difference results in the neutron spectrum difference such that is shown in Fig. 6.

Since the main contributing nuclides to the difference are ^{238}U, ^{239}Pu and ^{240}Pu, the calculations were firstly carried out by using the three data libraries based on ENDF/B-VI.8 but the data for ^{238}U, ^{239}Pu or ^{240}Pu are from JENDL-3.3, respectively. As a result, the data replacement of ^{239}Pu and ^{240}Pu does not have an effect at all on multiplication factor and void reactivity. On the other hand, by replacing ENDF/B-VI.8 ^{238}U data by JENDL-3.3, both multiplication factor and void reactivity values approach

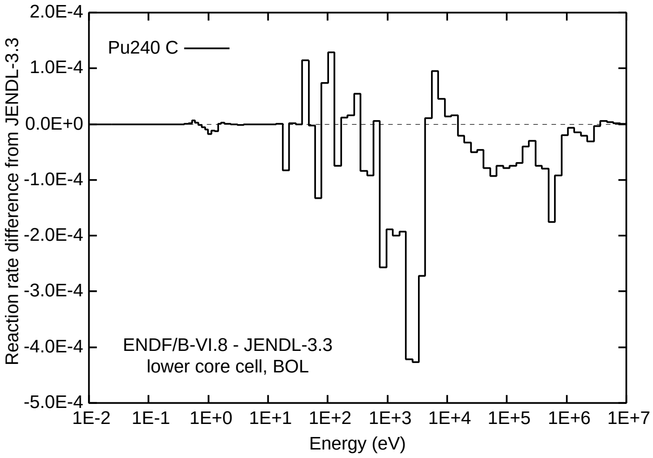

Fig. 7 ^{240}Pu capture rate difference between ENDF/B-VI.8 and JENDL-3.3 in lower core cell.

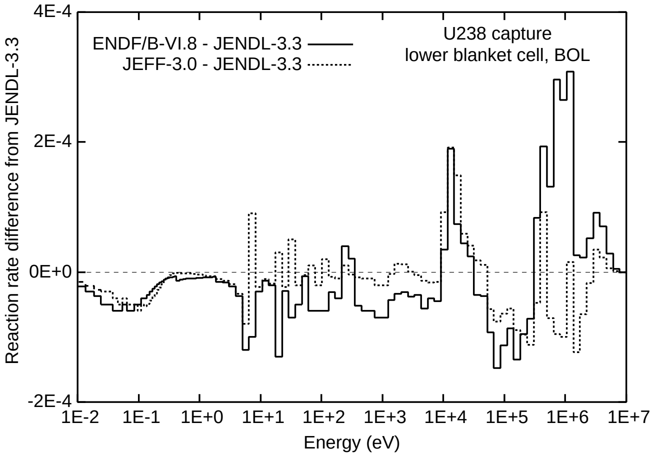

Fig. 8 ^{238}U capture rate difference between the nuclear data libraries in lower blanket cell.

to a large extent to the JENDL-3.3 results : The multiplication factor becomes about 1% smaller by using JENDL-3.3 ^{238}U data, and the void reactivity coefficient by about 1×10^{-4}dk/k/%void more negative.

From these results, the fast neutron spectrum difference between ENDF/B-VI.8 and JENDL-3.3 calculations seems to be caused mainly by the ^{238}U data. The calculation was next made by using such library that is based on ENDF/B-VI.8 and only the inelastic scattering cross section of ^{238}U is replaced by JENDL-3.3 data. Figures 9 and 10 show the calculated multiplication factor and void reactivity as a difference from JENDL-3.3 in the lower core cell by using this library ("ENDF/B-VI.8 + U8inJ33") in comparison with those obtained with the libraries based on ENDF/B-VI.8 and ENDF/B-VI.8 but for

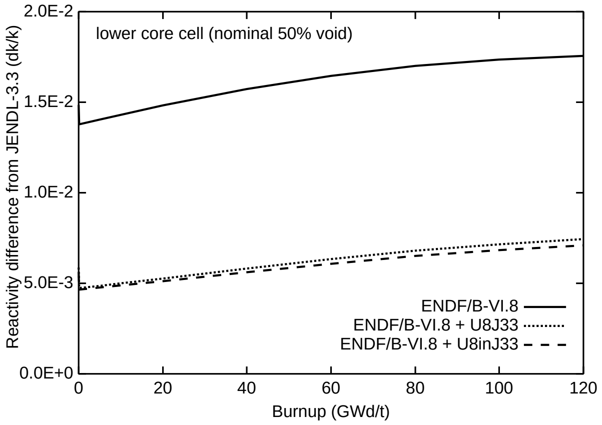

Fig. 9 Infinite multiplication factor difference from JENDL-3.3 in lower core cell calculated with different nuclear data libraries for ^{238}U.

^{238}U from JENDL-3.3 ("ENDF/B-VI.8 + U8J33"). In these figures, the effect of ^{238}U data on multiplication factor and void reactivity is shown to totally come from inelastic scattering cross section. The neutron spectrum difference between ENDF/B-VI.8 and JENDL-3.3 calculations at around 1MeV also decreases very much by replacing ^{238}U inelastic scattering cross section (Fig. 11).

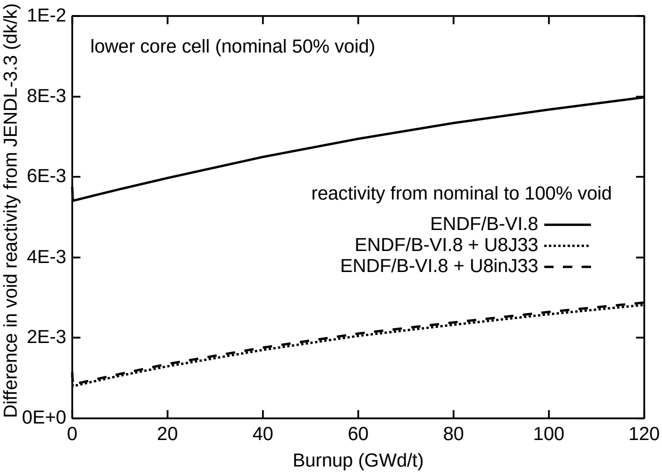

Fig. 10 Void reactivity difference from JENDL-3.3 in lower core cell for nominal to 100% void fraction change calculated with different nuclear data libraries for ^{238}U.

6. Summary

Reactor physics characteristics were calculated on the 1-dimensional axially heterogeneous Reduced Moderation Water Reactor (RMWR) core model by using the nuclear data libraries JENDL-3.3, ENDF/B-VI.8 and JEFF-3.0, and the effect of nuclear data uncertainty was studied.

As a result, ENDF/B-VI.8 was found to give nearly 1.5% larger effective multiplication factor, and more positive void reactivity coefficient by about 1.5×10^{-4}dk/k/%void, than JENDL-3.3. The differences are very important in the RMWR core design study, and caused mainly due to the difference in the fast neutron spectrum calculated with ENDF/B-VI.8 and JENDL-3.3. The difference in conversion ratio calculated with the libraries is not so large as in the multiplication factor and void reactivity cases, but the source of the difference seems to be in all fast to thermal energy regions.

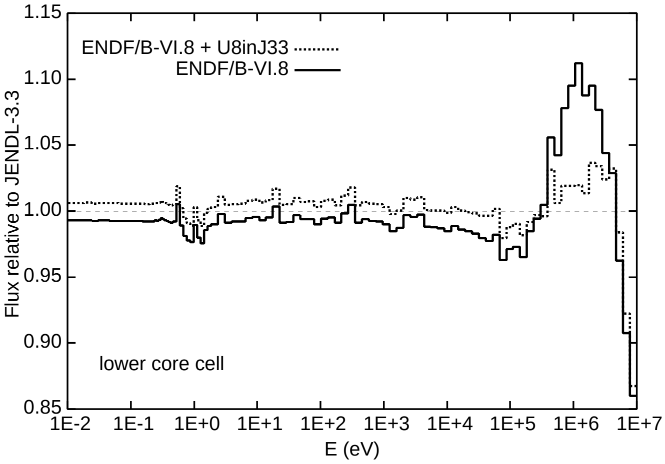

Fig. 11 Neutron spectrum in lower core cell calculated with different nuclear data libraries for ^{238}U. relative to the spectrum obtained with JENDL-3.3.

From the results obtained here, it can be said that the nuclear data in all fast, resonance and thermal energy regions are important in the RMWR core design study for a precise estimation of the important integral parameters such as multiplication factor, void reactivity and conversion ratio.

From the library effect study on the most important differences in multiplication factor and void reactivity between ENDF/B-VI.8 and JENDL-3.3, the main cause was found to be the inelastic scattering cross section of ^{238}U.

References

[1] K. Okumura, K. Kaneko and K. Tsuchihashi : "SRAC95; General Purpose Neutronics Code System", JAERI-Data/Code 96-015 (1996) [in Japanese].