2.4.4 Nuclear Data Usage for Research Reactors

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Abstract

In the department of research reactor, many neutronics calculations have been performed to construct, to operate and to modify research reactors of JAERI with several kinds of nuclear data libraries. This paper presents latest two neutronic analyses on research reactors. First one is design work of a low enriched uranium (LEU) fuel for JRR-4 (Japan Research Reactor No. 4). The other is design of a uranium silicon dispersion type (silicide) fuel of JRR-3M (Japan Research Reactor No. 3 Modified). Before starting the design work, to estimate the accuracy of computer code and calculation method, experimental data are calculated with several nuclear data libraries. From both cases of calculations, it is confirmed that JENDL-3.2 gives about 1 %Δk/k higher excess reactivity than JENDL-3.1.

1. General Description of Research Reactors

1.1 JRR-4

JRR-4 is a swimming pool type, light water cooled and moderated research reactor with maximum thermal output of 3.5 MW. Present core configuration is shown in Figure-1. The reactor core consists of 20 fuel elements, graphite reflector elements, irradiation pipes, a neutron source, control rods and backup rods. The fuel element now in use is aluminum cladded plate type, 93% ^{235}U enriched and fuel meat material is U-Al alloy. The new fuel has same dimensions but the fuel meat material is U_3Si_2-Al and ^{235}U enrichment is reduced to about 20%. Figure-2 shows the horizontal cross section of the fuel. The fuel consists of 15 fuel plates. An outside plate of each side contains half of other thirteen plates because of a request from thermal-hydraulics. Uranium density of the inner plate will be 3.8 g/cm^3.

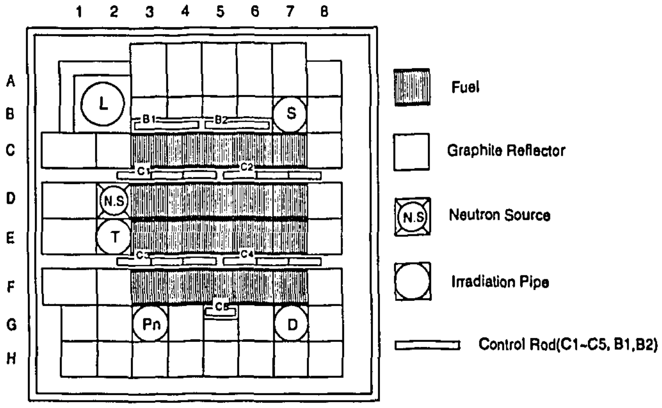

Fig.-1 JRR-4 Present Core Configuration

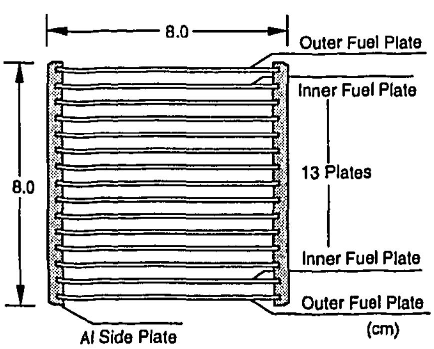

Fig.-2 Horizontal Cross Section of the Fuel Element

1.2 JRR-3M

JRR-3M is the latest research reactor in Japan. It achieved first criticality in March 1995 after the modification of old JRR-3. It is a swimming pool type, light water cooled and moderated research reactor with maximum thermal output of 20MW. The core consists of 26 standard fuel elements, 6 control elements with follower fuel elements, irradiation elements, beryllium reflector, heavy water reflector tank and neutron beam tubes. Figure-3 shows horizontal cross section of the core. The reactor uses ETR type fuel element with 20 fuel plates. The fuel meat is 20% enriched uranium aluminum dispersion type fuel (aluminide fuel) cladded with aluminum. It will be changed to 20% enriched uranium silicon dispersion type fuel (silicide fuel) with about 1.5 times of uranium loading and burnable poison to suppress the excess reactivity. Higher uranium loading enables higher burnup of discharged fuel and decreases the number of spent fuels.

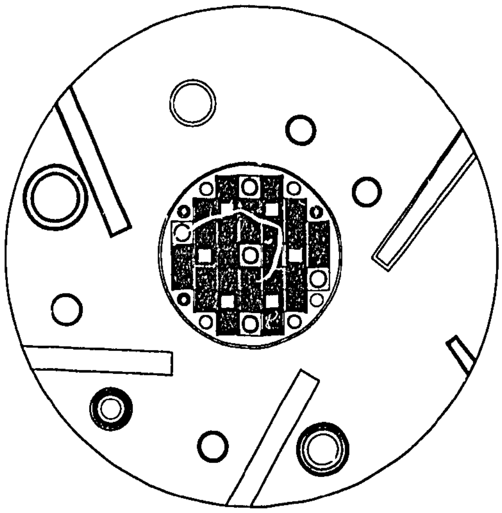

Fig.-3 JRR-3M Core Configuration

2. Calculation

Computer codes used in the calculation are SRAC Code System[1] and MVP Code[2]. Nuclear data libraries are ENDF/B-IV[3], JENDL-2[4], JENDL-3.1[5] and JENDL-3.2[6]. For the calculation of JRR-4, SRAC and MVP codes are used. Before starting the design calculation of LEU fuel, JRR-4 HEU core at the commissioning test is analyzed to estimate the accuracy of the codes and methods. It is also big purpose to see how much is the change when nuclear data library is changed. For the JRR-3M calculation, experimental data of initial critical test is analyzed with MVP code to estimate the accuracy of the code and method.

2.1 Calculation of JRR-4

2.1.1 Calculation with SRAC

The first step of the calculation is cell calculation of fuel element. Collision probability method is used in this step. Figure-4 shows calculation model of the fuel plate cell. One dimensional fixed source problem is solved with 107 group energy structure. Homogenized cross section of the plate cell is obtained. The next is cell calculation of the fuel element. Two dimensional fixed source problem is solved. The cross section of plate cell obtained in the previous calculation is used for this calculation. The number of energy group is 107. Figure-5 shows calculation model of the fuel element. From this calculation, homogenized cross section of the fuel element is obtained and energy group structure is collapsed from 107 to 6 or 8

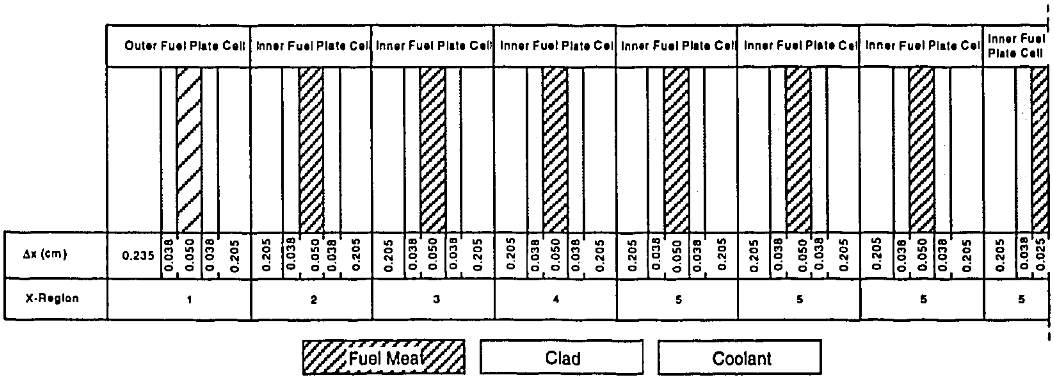

Fig.-4 Plate Cell Calculation Model

group.

The second step is generation of few group cross section of reflector, irradiation pipe and other reactor core elements. To obtain the neutron spectra as weighting functions for the energy group collapsing, two dimensional diffusion calculation of the core is performed with 107 energy group. From this calculation, element and space dependent neutron spectra are obtained. Cross sections of the elements are collapsed using the spectra.

The third step is whole core calculation using three dimension diffusion theory. Effective multiplication factor, control rod worth, neutron flux and so on are obtained from this step.

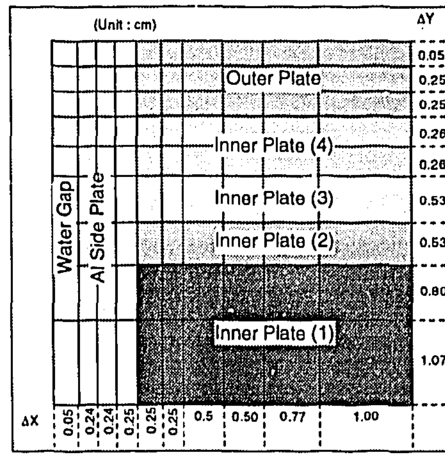

Fig.-5 Element Cell Calculation Model

2.1.2 Calculation with MVP

MVP is a continuous energy monte carlo code. It can treat JRR-4 core with fewest geometrical approximations. Active part of the fuel element is described exactly in the calculation. Other parts of the fuel elements and other core elements are divided into several horizontal planes and homogenized by atom number density in order to reduce geometrical complexity. Calculation is continued until small enough deviation is obtained.

2.2 Calculation of JRR-3M

2.2.1 Calculation with MVP

Active part of the fuel element is treated exactly. Other parts of the fuel element are divided into several horizontal planes and homogenized by atom density. Irradiation elements in the core, irradiation facilities in the D2O reflector tank, detectors in the core and reflector, beam tubes in the D2O reflector tank and other core elements are taken into account for the calculations as exactly as possible.

3. Results

3.1 JRR-4

Table-1 is the excess reactivity(k_{eff}, effective multiplication factor) of A-12 core calculated with MVP. A-12 core is the first critical core of JRR-4. The core consists of twelve A-type fuels. There are two kinds of HEU fuel for JRR-4. JRR-4 have been operated with maximum thermal output of 2.5MW using A-type HEU fuel elements for 10 years since the initial criticality. When the maximum power increased to 3.5 MW, B-type fuel elements were adopted and have been used since 1976. Table-1 shows MVP with JENDL-3.1 slightly underestimates the experimental value and gives a good C/E value. The combination of MVP and JENDL-3.2 overestimates the experimental value for 0.6%Δk/k and gives about 0.9%Δk/k higher excess reactivity than JENDL-3.1.

Table-2 is the results of criticality calculation of A-4+B-12 core. The core consists of four A-type elements and twelve B-type elements. JENDL-3.1 underestimates experimental data for about 0.6%Δk/k and JENDL-3.2 overestimates it for about 4%Δk/k. Difference between two libraries is about 1.0%Δk/k.

Table-3 is the results of excess reactivity of silicide core. SRAC code gives about 0.4%Δk/k lower reactivity than MVP. JENDL-3.2 gives about 0.8%Δk/k higher reactivity than JENDL-3.1.

Table-4 is results of excess reactivity calculation of a different kind of silicide core. This is a temporary core under the parameter survey calculation to decide the final uranium density. Uranium density of the inner plate of the core is 4.0g g/cm^3. (Final uranium density of the inner plate is 3.8 g/cm^3) From the table, it can be seen that ENDF/B-IV and JENDL-3.1 shows good agreement. JENDL-2 gives higher reactivity than other two libraries.

Table-1 Excess Reactivity of JRR-4 A-12 Core Calculated with MVP

	JENDL-3.1	JENDL-3.2	EXPERIMENT
k_{eff}	0.9948 (0.120%)	1.0035 (0.086%)	0.9972
C/E	0.9976	1.0063	-----
$\Delta\rho$(J3.2-J3.1)	0.877 %Δk/k		-----

Table-2 Criticality of JRR-4 A-4+B-12 Core Calculated with MVP

	JENDL-3.1	JENDL-3.2	EXPERIMENT
k_{eff}	0.9933 (0.136%)	1.0030 (0.125%)	0.9995
C/E	0.9938	1.0035	-----
$\Delta\rho$(J3.2-J3.1)	0.974 %Δk/k		-----

Table-3 Excess Reactivity of JRR-4 Silicide Core

CODE	SRAC		MVP	
LIBRARY	JENDL-3.1	JENDL-3.2	JENDL-3.1	JENDL-3.2
k_{eff}	1.1043	1.1144	1.1091 (0.103%)	1.1197 (0.104%)
$\Delta\rho$(J3.2-J3.1)	0.821%Δk/k		0.852%Δk/k	
SRAC/MVP	0.9957	0.9953	-----	-----

Table-4 Excess Reactivity of JRR-4 Silicide Core (II)

	ENDF/B-IV	JENDL-3.2	JENDL-3.1
k_{eff}	1.1191	1.1266	1.1184
JENDL/ENDF/B-IV	-----	1.0067	0.9994

3.2 JRR-3M

Table-5 is excess reactivity of initial critical core calculated with MVP. Calculation with JENDL-3.1 slightly overestimates the experimental value. JENDL-3.2 gives more than 1%Δk/k higher excess reactivity than JENDL-3.1. It has been known that resonance absorption cross section of U-235 of JENDL-3.2 may be too small[7]. To confirm that the difference between two libraries is caused from U-235 or not, a calculation with JENDL-3.2 library but only the data of U-235 is changed to JENDL-3.1. As a result of the calculation, difference from the JENDL-3.1

calculation cannot be seen and it is confirmed that the dominant reason of the difference between two libraries is the data of JENDL-3.2.

Table-6 is results of criticality calculation of initial full core of JRR-3M. It shows same tendency as Table-5. JENDL-3.1 overestimates the experimental data and JENDL-3.2 gives about 1%Δk/k higher reactivity than JENDL-3.1. Combined library of JENDL-3.2 and U-235 of JENDL-3.1 shows good agreement with JENDL-3.1.

Table-5 Excess Reactivity of JRR-3M First Critical Core Calculated with MVP

NUCLEAR DATA	JENDL-3.1	JENDL-3.2 + ^{235}U of JENDL-3.1	JENDL-3.2	EXPERIMENT
k_{eff}	1.0018 (0.087%)	1.0022 (0.092%)	1.0132 (0.095%)	0.9988
C/E	1.0030	1.0034	1.0144	-----
Δρ(J3.2-J3.1)	-----	0.040%Δk/k	1.123%Δk/k	-----

Table-6 Criticality of JRR-3M Initial Full Core Calculated with MVP

NUCLEAR DATA	JENDL-3.1	JENDL-3.2 + ^{235}U of JENDL-3.1	JENDL-3.2	EXPERIMENT
k_{eff}	1.0056 (0.080%)	1.0059 (0.101%)	1.0156 (0.091%)	0.9993
C/E	1.0063	1.0066	1.0163	-----
Δρ(J3.2-J3.1)	-----	0.030%Δk/k	0.979%Δk/k	-----

4. Conclusions

Calculations on JRR-4 and JRR-3M cores with JENDL-3.1 and JENDL-3.2 libraries have been performed and followings were shown.

JENDL-3.1 gives good C/E value in almost of the calculated cases. JENDL-3.2 gives about 1%Δk/k higher reactivity than JENDL-3.1. JENDL-3.1 shows good agreement with ENDF/B-IV. JENDL-2 gives higher reactivity than ENDF/B-IV and JENDL-3.1.

In case of JRR-4, JENDL-3.1 underestimates the experimental data and JENDL-3.2 overestimates it.

In case of JRR-3M, both of JENDL-3.1 and JENDL-3.2 overestimate the experimental value. Calculations with JENDL-3.2 but only the data of U-235 is changed to JENDL-3.1 have been done. The results are not different from the results of calculations with JENDL-3.1 for all nuclides. It is confirmed that difference between two libraries is caused from the U-235 data of JENDL-3.2.

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