JENDL-3.2 Performance in Analyses of MISTRAL Critical Experiments for High-Moderation MOX Cores

Naoyuki TAKADA
Fuel Engineering and Development Department, Nuclear Fuel Industries, Ltd.
3135-41, Muramatsu, Tokai-mura, Naka-gun, Ibaraki, 319-1196 Japan
E-mail: takada@nfi.co.jp

Koki HIBI(MHI), Kazuya ISHII(Hitachi), Yoshihira ANDO(Toshiba),
Toru YAMAMOTO, Masao UEJI, Yutaka IWATA(NUPEC)

NUPEC and CEA have launched an extensive experimental program called MISTRAL to study highly moderated MOX cores for the advanced LWRs. The analyses using SRAC system and MVP code with JENDL-3.2 library are in progress on the experiments of the MISTRAL and the former EPICURE programs. Various comparisons have been made between calculation results and measurement values.

1. Introduction

Nuclear Power Engineering Corporation (NUPEC), French Atomic Commission (CEA) and CEA's industrial partners have launched an extensive experimental program called MISTRAL (MOX: Investigation of Systems Technically Relevant of Advanced Light water reactors) [1,2,3,4] in order to obtain basic core physical parameters of highly moderated MOX cores that will be used to improve core analysis methods. NUPEC is conducting this study on behalf of the Japanese Ministry of International Trade and Industry (MITI). This experimental program has been executed in the EOLE facility at Cadarache center. The MISTRAL program consists of 4 core configurations and has been successfully completed by July 2000. As a part of the MISTRAL program, NUPEC also obtained some of the experimental data of the EPICURE program that CEA had conducted for 30% MOX loading in PWRs.

2. EOLE critical facility

Experiments have been performed in the EOLE facility that is a tank type critical facility. A cylindrical Aluminum vessel (diameter = 2.3 m, height = 3m) is installed with stainless steel over structures. Fuel pins used in the facility are standard PWR types and the active length of the pin is about 80 cm. Four types of enrichment are prepared for MOX pins and one type for UO_2 pin. Grid plates are fixed inside the inner tank and they provide flexibility of the core configurations. The reactivity of the core is controlled mainly with boron (boric acid) concentration in water and core size. During the critical experiments, a water level of the tank is always kept at the height that is on approximately 20 cm above from the top of active length of fuel pins. Small reactivity is compensated using a pilot rod. Core excess reactivity without the pilot rod is determined through the in-hour equation with measuring the doubling time after the withdrawal of the pilot rod. Four pairs of cluster-type safety rods are utilized only for the shutdown.

3. Core configurations and measurements in the MISTRAL program

Figure 1 shows the core configuration of MISTRAL-1. It consisted of about 750 regular enriched UO_2 (3.7% in ^{235}U) fuel pins in a lattice pitch of 1.32 cm and was designed as a reference for the highly moderated MOX cores. Figure 2 shows the core configuration of MISTRAL-2. This is a highly moderated full-MOX core consisting of about 1600 MOX (7% enrichment) fuel pins with the same lattice pitch of MISTRAL-1. Figure 3 shows the core configuration of MISTRAL-3 which is devoted to the physical study of a 100% MOX lattice with higher moderation than MISTRAL-2. This configuration consists of about 1350 MOX 7% fuel pins in the lattice pitch of 1.39 cm. Figure 4 shows the Core configuration of MISTRAL-4 which is a PWR mock-up configuration. A couple of measurement items were selected for each core configuration from following items:

(1) Critical mass and boron concentration
(2) Buckling measurement using reaction rate distribution measurements
(3) Boron worth
(4) Spectrum indices measurement
(5) Modified conversion factor, 238U capture/total fission
(6) Isothermal temperature coefficients
(7) Reactivity worth and associated reaction rate distribution of a single absorber (Natural B_4C, enriched B_4C, Ag-In-Cd alloy, and UO_2-Gd_2O_3) at the center of the core
(8) Reactivity worth and associated reaction rate distribution of the substitution of 9 central fuel pins by water holes

(9) Reactivity worth and associated reaction rate distribution of a cluster absorber
(10) Void coefficient
(11) β eff

4. Experimental methods

The number of fuel pins, core, temperature, the boron concentration and doubling time were measured to determine the core critical mass. Various kinds of experimental methods were applied to obtain physical parameters of the cores in the MISTRAL program as described below. A neutron source multiplication method (a sub-critical method) was utilized for the reactivity measurement. An integral gamma scanning method was applied to determine the fission densities of the fuel pins. Miniature fission chambers of several kinds of isotopes were adopted for the determination of energy dependent neutron flux and also for spectrum index measurements. The effective delayed neutron fraction of a core (β eff) was measured using of the core noise method which had been utilized in the international benchmark of β eff's at the MASURCA and the FCA fast critical facilities.

5. Calculation methods

The analysis has been performed using SRAC system and MVP with JENDL-3.2 library which were developed at Japan Atomic Energy Research Institute (JAERI). SRAC system consists of deterministic codes. A processed nuclear data library with 107-energy group structure is prepared for SRAC. MVP is a continuous energy Monte Carlo code that is utilized to obtain reference calculation results for the SRAC system such as core eigen-values. In SRAC system, the collision probability method is applied for generating the 16-group collapsed and homogenized unit cell cross sections. The neutron energy spectrum affected by the neutron leakage is calculated with the B1 approximation taking into account the measured geometrical buckling. The resonance absorption of Pu isotopes should be precisely evaluated at epi-thermal and thermal ranges for MOX fuels. Therefore, an ultra fine group resonance reaction calculation module, PEACO, is utilized throughout calculation of effective cross section. The thermal cut-off energy was carefully chosen and determined to be 1.855eV through a sensitivity study. After generating 16-group cell cross sections (fast range - 8 groups and thermal range - 8 groups) , core calculations in 1/4 symmetry configuration were performed using CITATION and/or TWOTRAN modules in SRAC system. In two-dimensional calculation model, axial leakage is implicitly taken into account using the measured axial buckling of a core. For a single absorber calculation, a 3×3 cell model is adopted in the collision probability calculation of the absorber cell at the core center. Also detailed cell models in the collision probability calculation are adopted for the analysis of spectrum indices.

6. Calculation results

Varieties of comparisons between calculations and measurements are in progress for MH1.2 (which is devoted to study on basic characteristics of a MOX core in the EPICURE program), MISTRAL-1, -2 and -3. Table 1 shows the differences of keffs for 4 configurations. The calculated keffs agree well with the experimental values. Table 2 shows the root-mean-square (R.M.S) differences of radial power distribution. The differences are as much as the uncertainty of measurement. Table 3 shows the C/E values of spectrum indices with two calculation methods. The differences of the C/E values obtained by two calculation methods are not large and the C/E tendency are same with two calculation methods.

Acknowledgment

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References

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Table.1 Differences of keff between Calculation and Measurement for each Experimental Core

PROGRAM	EPICURE	MISTRAL	MISTRAL	MISTRAL
CORE NAME	MH1.2	CORE1	CORE2	CORE3
FEATURE	Partial MOX	Uranium CORE	Full MOX	Full MOX
FUEL PIN	3.7%UO2 + 7% MOX	3.7% UO2	7% MOX (Mainly)	7% MOX
H/HM	3.7	5.1	5.1	6.2
CORE DIAMETER	69 cm	41 cm	60 cm	59 cm
MVP	＋ 0.27 %Δk ±0.02 % (1σ)	＋ 0.48 %Δk ±0.03 % (1σ)	＋ 0.70 %Δk ±0.02 % (1σ)	＋ 0.77 %Δk ±0.02 % (1σ)
SRAC (Pij + TWOTRAN)	＋ 0.13 %Δk	－ 0.19 %Δk	＋ 0.41 %Δk	＋ 0.42 %Δk

Table. 2 R.M.S Differences of Radial Power Distribution between Calculation and Measurement for each Experimental Core

PROGRAM	EPICURE	MISTRAL	MISTRAL	MISTRAL
CORE NAME	MH1.2	CORE1	CORE2	CORE3
FEATURE	Partial MOX	Uranium CORE	Full MOX	Full MOX
MVP	1.2 %	1.7 %	1.7 %	1.4 %
SRAC (Pij + CITATION)	0.9 %	2.0 %	1.1 %	1.3 %

Measurement uncertainty UO2 rod ～1.0 % : MOX rod ～ 1.5 % (1σ)

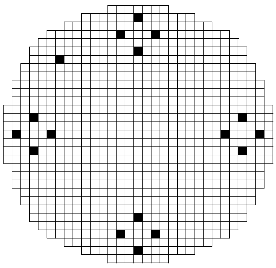
Table. 3 C/E Values of Spectrum Indices with Two Calculation Methods

CORE NAME		CORE1			CORE2		
Calculation method**		SRAC	MVP	uncertainty*	SRAC	MVP	uncertainty*
SPECTRUM INDICES	238U/235U***	0.67	0.63	(10%)	0.90	0.87	(6.7%)
	239Pu/235U	1.01	1.00	(2.4%)	1.04	1.01	(2.4%)
	238Pu/239Pu	–	–	–	0.94	0.94	(13.7%)
	240Pu/239Pu***	0.95	0.91	(7.5%)	0.83	0.81	(5.9%)
	241Pu/239Pu	0.99	1.00	(2.7%)	0.98	0.99	(2.7%)
	242Pu/239Pu	–	–	–	0.98	0.96	(7.6%)
	237Np/239Pu***	0.76	0.74	(3.2%)	0.90	0.88	(3.2%)

* ( ) measurement uncertainty (1σ)

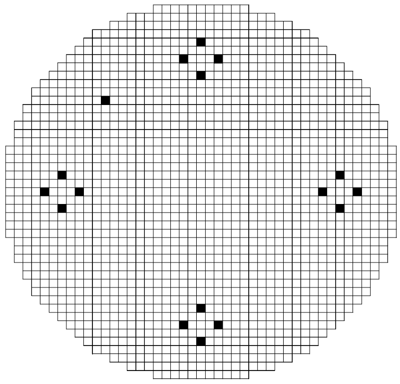
** Calculation method
SRAC Code: Collision Probability Calculation (107 energy group)
MVP Code: Continuous energy Monte Carlo Calculation

*** These measurement values are now under investigation.



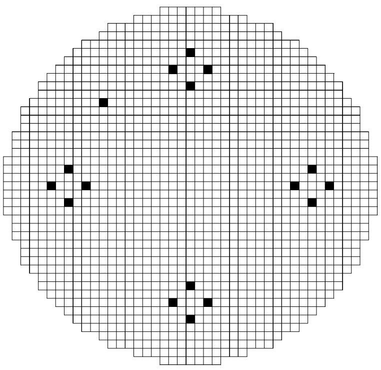
□ MOX(7.0%) fuel rod
■ Guide tube for safty and control rod

Fig.1 Core Configuration of MISTRAL-1



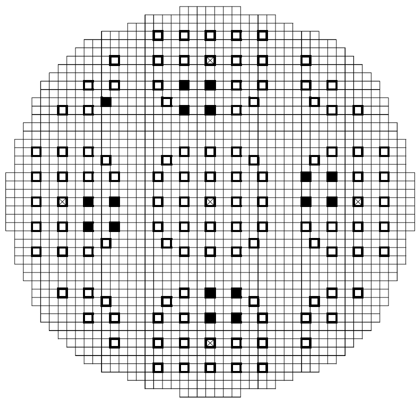
□ MOX(7.0%) fuel rod
□ MOX(8.7%) fuel rod
■ Guide tube for safty and control rod

Fig.2 Core Configuration of MISTRAL-2



□ MOX(7.0%) fuel rod
■ Guide tube for safty and control rod

Fig.3 Core Configuration of MISTRAL-3



□ MOX(7.0%) fuel rod
□ Mock-up thimble tube
⊠ Instrumentation tube
■ Guide tube for safty and control rod

Fig.4 Core Configuration of MISTRAL-4