The MOX core critical experiments for LWRs and the analysis based on JENDL-3.2

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NUPEC and CEA have launched an extensive experimental program called MISTRAL to study highly moderated MOX cores for the advanced LWRs. The analyses with using SRAC system and MVP with JENDL-3.2 library are progressing 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] in order to obtain the core physics parameters of high moderation MOX cores that will be used to improve the core analysis methods. NUPEC is conducting this study on behalf of the Japanese Ministry of International Trade and Industry (MITI). This experimental program is progressing in the EOLE facility at CEA Cadarache center. This program started in 1996 and scheduled to be finished by 2000. Among four cores of the program, the experiments of Core 1 and Core 2 have already been finished by the end of April in 1998. Within a part of collaboration of NUPEC and CEA, NUPEC also obtained the experimental data of the EPICURE program that CEA has conducted for 30% MOX loading in PWRs. Figure 1 shows UH1.2 core configuration that was devoted to study on a UO_2 reference core in the

EPICURE program. Figure 2 shows MH1.2 core configuration that was devoted to study on basic characteristics of a MOX core in the EPICURE program.

2. EOLE critical facility

Experiments have been performed in the EOLE facility that is a tank type critical assembly. A cylindrical Aluminum vessel (diameter = 2.3 m, height = 3m) is installed with stainless steel over structures. Fuel pins of 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 in an inner tank and they provide flexibility of the core configurations. The reactivity of a core is controlled mainly with boron (boric acid) concentration in water and core size. At the critical states and the various measurements, the water level of the tank is always kept at the height that is about 20 cm higher from the top of active length of fuel pins. Small reactivity is compensated with the use of a pilot rod. Core excess reactivity without the pilot rod is determined through the inhour equation with measuring the doubling time after withdrawal of the pilot rod. Four pairs of cluster-type safety rods are utilized for the shutdown.

3. Core configurations and measurements in the MISTRAL program

Figure 3 shows the core configuration of MISTRAL Core 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 high moderation MOX cores. Figure 4 shows the core configuration of Core 2. This is a high moderation full-MOX core consisting of about 1600 MOX (7% enrichment) fuel pins in the same lattice pitch of Core 1. Core 3 is devoted to the physical study of a 100% MOX lattice with higher moderation than Core 2. This configuration consists of about 1350 MOX 7% fuel pins in the lattice pitch of 1.39 cm. Core 4 is a PWR mock-up configuration. The measurement items are selected for each core configuration from following items:

(1) Critical mass and boron concentration

(2)Buckling measurement with 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

Various kinds of experimental methods are applied to obtain physical parameters of the cores in the MISTRAL program. The number of fuel pins, core, temperature, the boron concentration and doubling time are measured to determine the core critical mass. A neutron source multiplication method (a sub-critical method) is utilized for the reactivity measurement. An integral gamma scanning method is applied to determine the fission densities of the fuel pins. Miniature fission chambers of several kinds of isotopes are adopted for the determination of energy dependent neutron flux and also for spectral index measurements. The effective delayed neutron fraction of a core (β eff) is measured with use of the core noise method which has 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 which were developed at JAERI. SRAC system is a deterministic type code. In SRAC, the processed 107-energy group's nuclear data library is prepared and the combination of a cell calculation and a core calculation is performed. The 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 the SRAC system, the conventional 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 the measured geometrical buckling into account. The resonance absorption reaction 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 fully utilized for the analysis. The thermal cut-off energy was carefully studied and determined to be 1.855eV. After generating 16-group cell cross sections (fast range - 8 groups and thermal range - 8 groups) , core calculations in 1/4 symmetry configuration are performed with the use of CITATION and TWOTRAN module of the SRAC system. In two-dimensional calculations, the axial leakage is calculated with 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 is adopted for the spectral indices analysis.

6. Calculation results

Varieties of comparisons between calculations and measurements are progressing for UH1.2, MH1.2, MISTRAL Core1 and 2. 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 spectral indexes and conversion factor. Two typical spectral indices and modified conversion factors show the agreement within two times of the uncertainty of measurement error.

Acknowledgment

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References

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Table.1 The differences of Keff between calculation and measurement for each experimental core

PROGRAM	EPICURE	MISTRAL	EPICURE	MISTRAL
CORE NAME	UH1.2	CORE1	MH1.2	CORE2
FEATURE	Uranium CORE	Uranium CORE	Partial MOX	Full MOX
FUEL PIN	3.7% UO2	3.7% UO2	3.7%UO2 + 7% MOX	7% MOX (Mainly)
H/HM	3.7	5.1	3.7	5.1
CORE DIAMETER	～ 50 cm	～ 40 cm	～ 70 cm	～ 60 cm
MVP	＋ 0.51 %Δk ±0.02 % (1σ)	＋ 0.39 %Δk ±0.03 % (1σ)	＋ 0.43 %Δk ±0.02 % (1σ)	＋ 0.65 %Δk ±0.02 % (1σ)
SRAC (Pij + TWOTRAN)	＋ 0.07 %Δk	－ 0.19 %Δk	＋ 0.29 %Δk	＋ 0.37 %Δk

Table. 2 The R.M.S differences of radial power distribution between calculation and measurement for each experimental core

PROGRAM	EPICURE	MISTRAL	EPICURE	MISTRAL
CORE NAME	UH1.2	CORE1	MH1.2	CORE2
FEATURE	Uranium CORE	Uranium CORE	Partial MOX	Full MOX
MVP	1.0 %	1.7 %	1.2 %	1.6 %
SRAC (Pij + CITATION)	0.8 %	2.0 %	0.9 %	1.3 %

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

Table. 3 The C/E values of spectral Indexes and modifies conversion factor for each experimental core

PROGRAM		EPICURE		MISTRAL	MISTRAL
CORE NAME		MH1.2		CORE1	CORE2
FEATURE		Partial MOX		Uranium CORE	Full MOX
FUEL PIN		3.7%UO2 + 7% MOX		3.7% UO2	7% MOX (Mainly)
H/HM		3.7		5.1	5.1
POSITION		UO2 REGION	MOX REGION	CENTER	CENTER
SPECTRAL INDICES	239Pu/235U	1.02 (2.0)	1.05 (2.1)	1.01 (2.4)	1.04 (1.5)
	241Pu/235U	0.96 (2.9)	0.97 (2.9)	1.00 (3.6)	1.02 (2.3)
CONVERSION FACTOR		－	－	1.02 (3.0)	1.01 (2.7)

Modified conversion factor ＝ (238U capture)／(Total Fission) , ( ) Measurement uncertainty % (1σ)

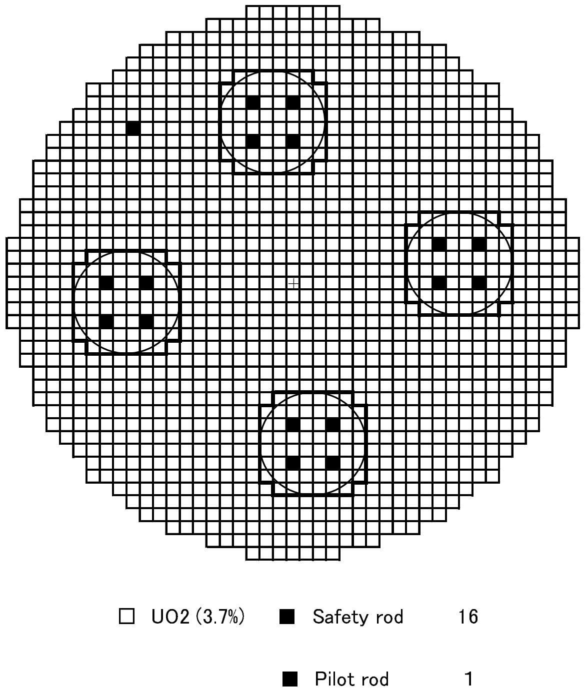

Fig. 1 The core configuration of UH1.2

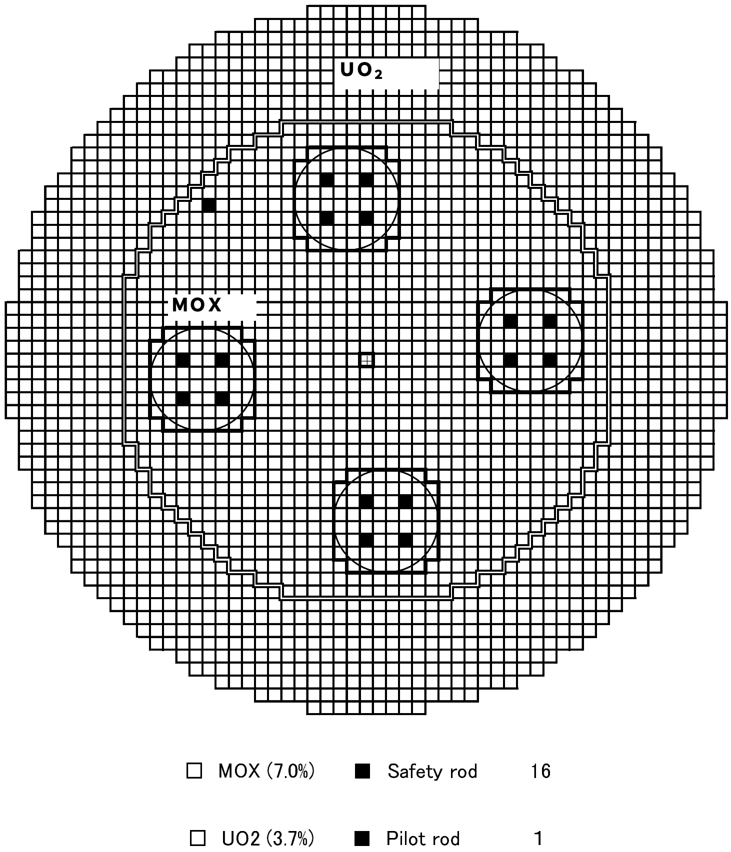

Fig. 2 The core configuration of MH1.2

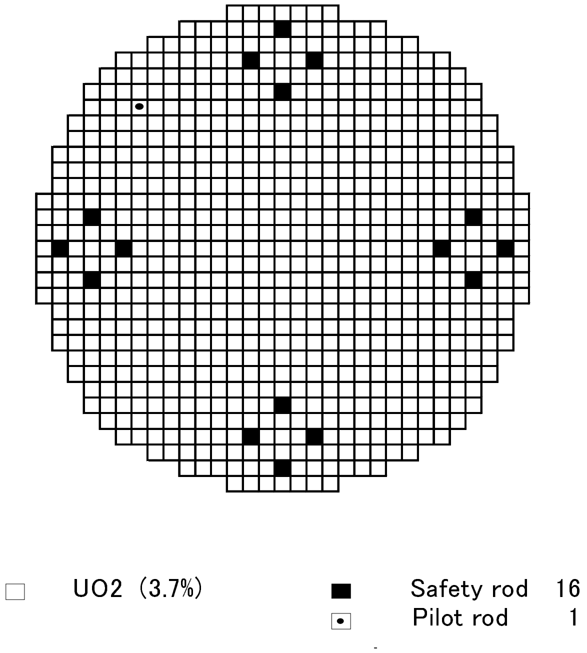

Fig. 3 The core configuration of MISTRAL-1

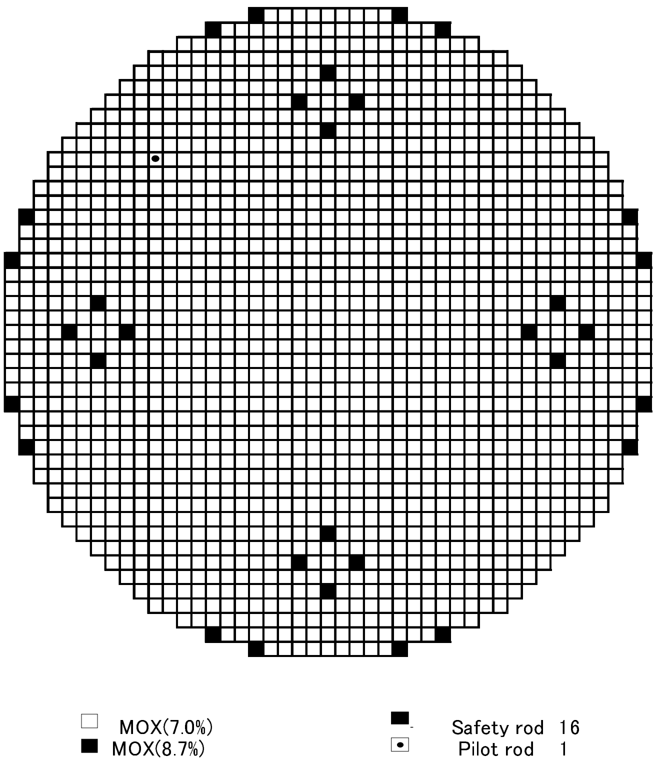

Fig.4 The core configuration of MISTRAL-2