Target accuracy of MA nuclear data and progress in validation by post irradiation experiments with the fast reactor "JOYO"

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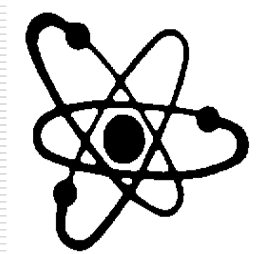


I. Objective

- Development of burnup calculation method for commercialized fast breeder reactors (FBRs)
- Validation of nuclear data for transmutation of minor actinide (MA)
- Improvement of the accuracy of capture cross-section for major actinides
- Feedback of PIE data to FBR core design by cross-section adjustment

Programme of PIE analysis at JNC

- JOYO MK-I driver fuel
- JOYO MK-II driver fuel
- MA samples irradiated at JOYO MK-II core

II. Target accuracy of MA nuclear data

- Nuclear-data-induced uncertainty was evaluated for reactor core parameters and fuel-cycle-related quantities.

600 MWe-
Conventional FBR
with LWR-MA 2.7% added
(Np/Am/Cm=49/46/5 (wt%))

Standard deviation $= \sqrt{\mathbf{GMG}^T}$

G : Sensitivity coefficient vector

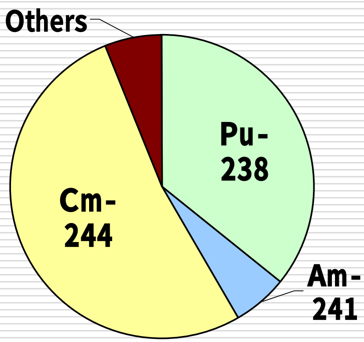
M : JENDL-3.2 covariance matrix (available for main nuclides)

Expanded in the space of nuclide, reaction, and energy group

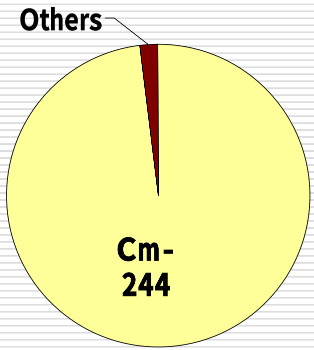
- Variance of MA nuclear data was tentatively deduced from discrepancies among the following libraries: JEF-2.2, ENDF/B-VI.5, and JENDL-3.3.

Decay heat, neutron emission, gamma energy from FBR spent fuel

- Source nuclides

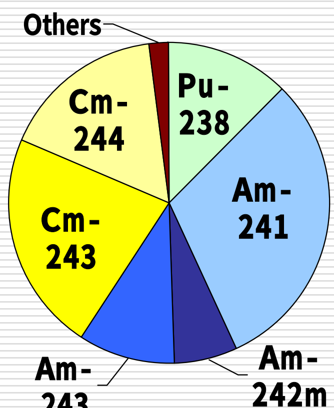


Decay heat



Neutron emission

<Conditions>
600MWe-FBR (Na-MOX),
Pu enrichment: 19 wt%,
LWR-MA 2.7 wt% added,
Burnups:130 GWd/t,
4-year cooled.



Gamma energy

- Discrepancy (1σ) from contributed reactions

Decay heat
Pu-238 Capture 1.2%
Am-241 Isomeric Ratio 1.2%
Am-243 Capture 2.4%
Cm-244 Capture 2.3%

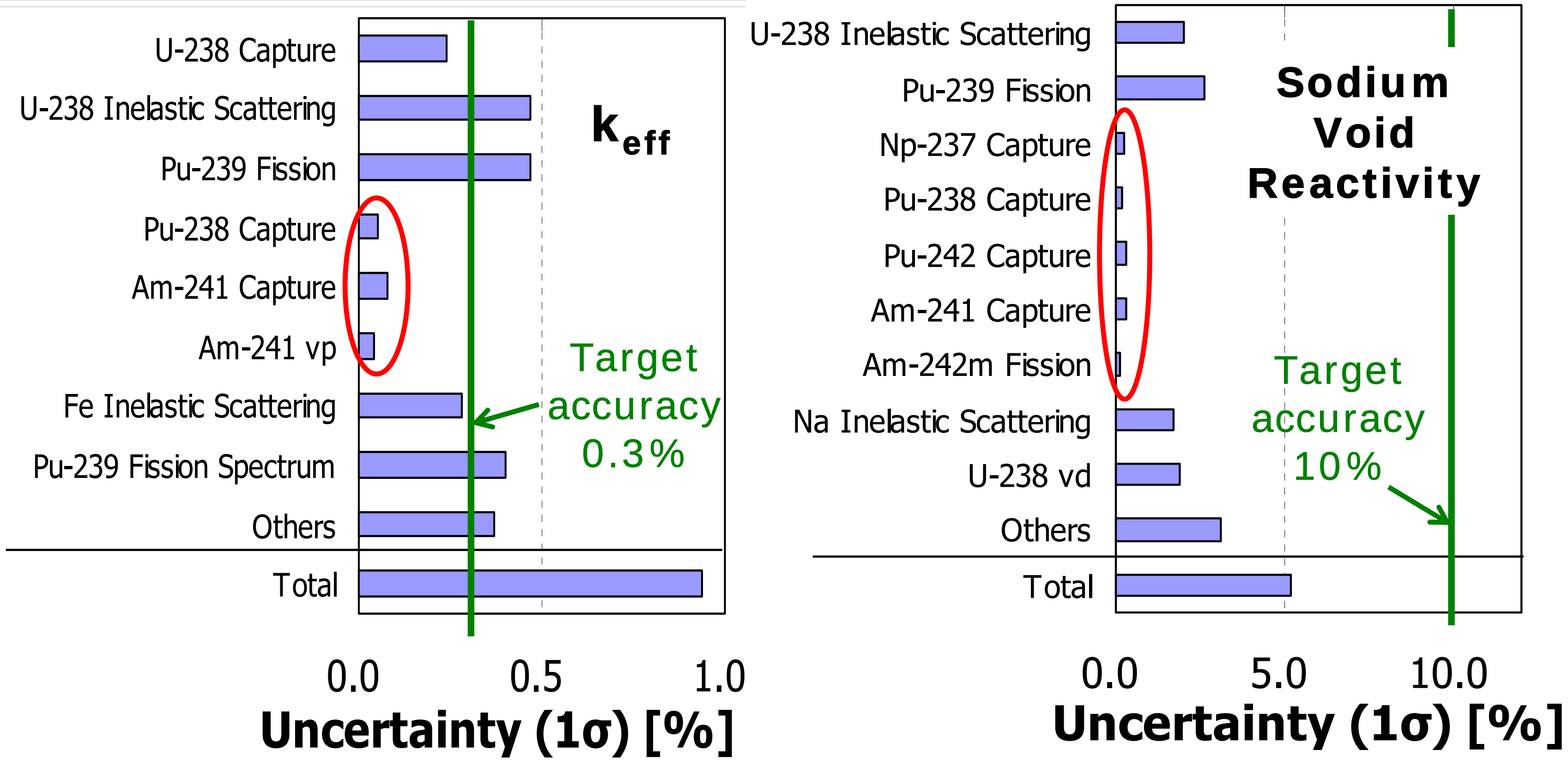
Neutron emission
Am-243 Capture 4.5%
Cm-244 Capture 4.4%

Gamma energy
Am-241 Capture 2.1%
Am-241 Isomeric Ratio 5.2%
Cm-242 Capture 6.9%
Cm-243 Fission 1.7%

※Target accuracy: 5～10%

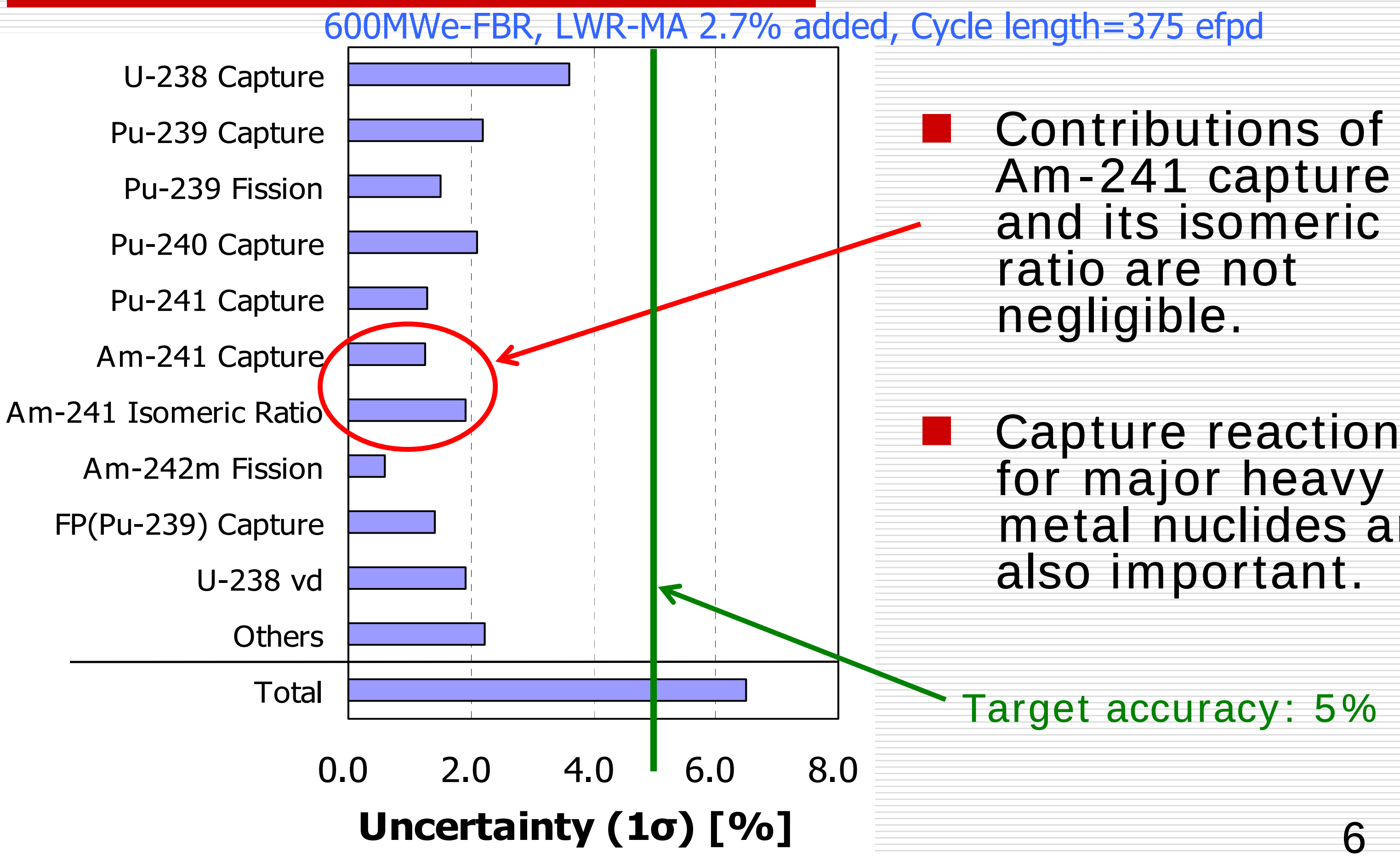
Criticality, Sodium void reactivity

600MWe-FBR, LWR-MA 2.7% added



◆ **MA nuclear data bring about small uncertainty.**

Burnup reactivity loss



- Contributions of Am-241 capture and its isomeric ratio are not negligible.
- Capture reactions for major heavy metal nuclides are also important.

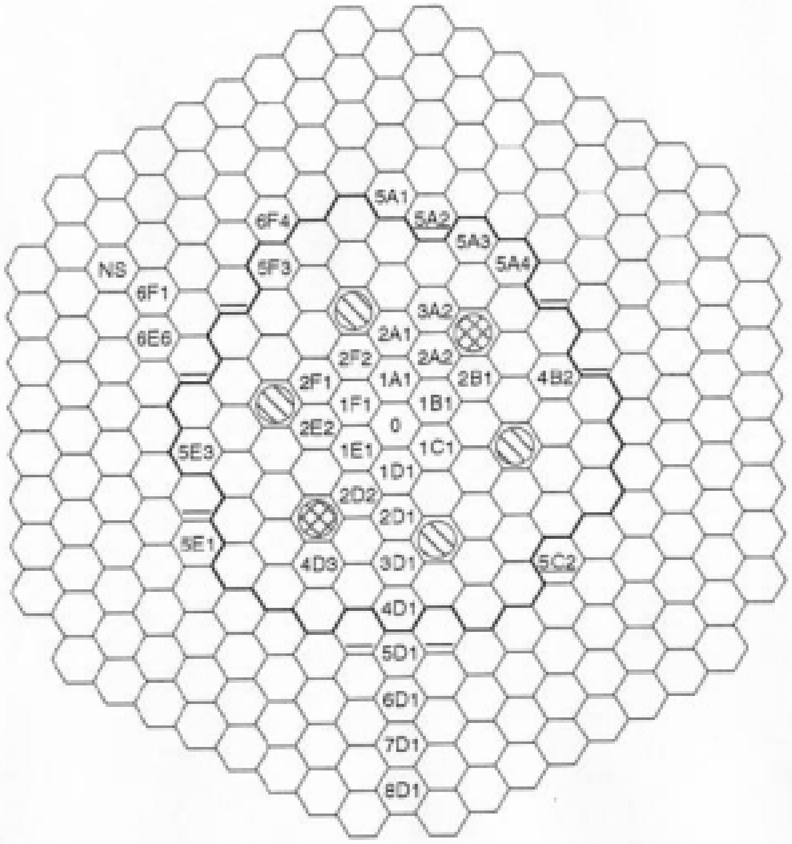
Target accuracy of MA nuclear data - Remarks -

- Important nuclides and reactions:

Am-241 Capture, Am-241 Isomeric Ratio,
Am-243 Capture, Cm-242 Capture,
Cm-244 Capture.

- MA data discrepancy has relatively small impact on conventional fast reactor cycle systems.
- However, there is no confidence that the discrepancy among libraries is equivalent to the actual uncertainty. → Need for measurement and validation works.
- Covariance files for MA are also required for a practical uncertainty evaluation in the future.

III Progress in PIE analysis (1)
- JOYO MK-I driver fuel -



MK-I driver fuel: MOX fuel

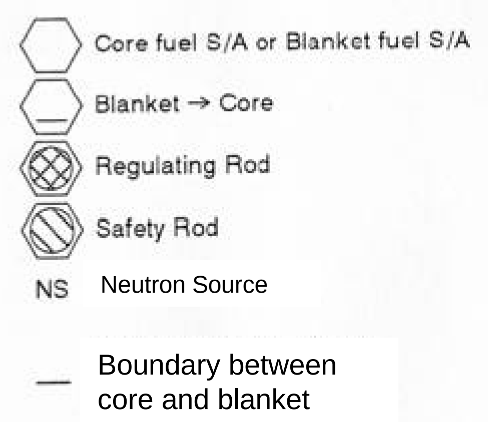
(^{235}U/U～23%, Pu/(U+Pu)～18**%**)

Operation period: 1978.4 – 1981.12

(11 cycles)

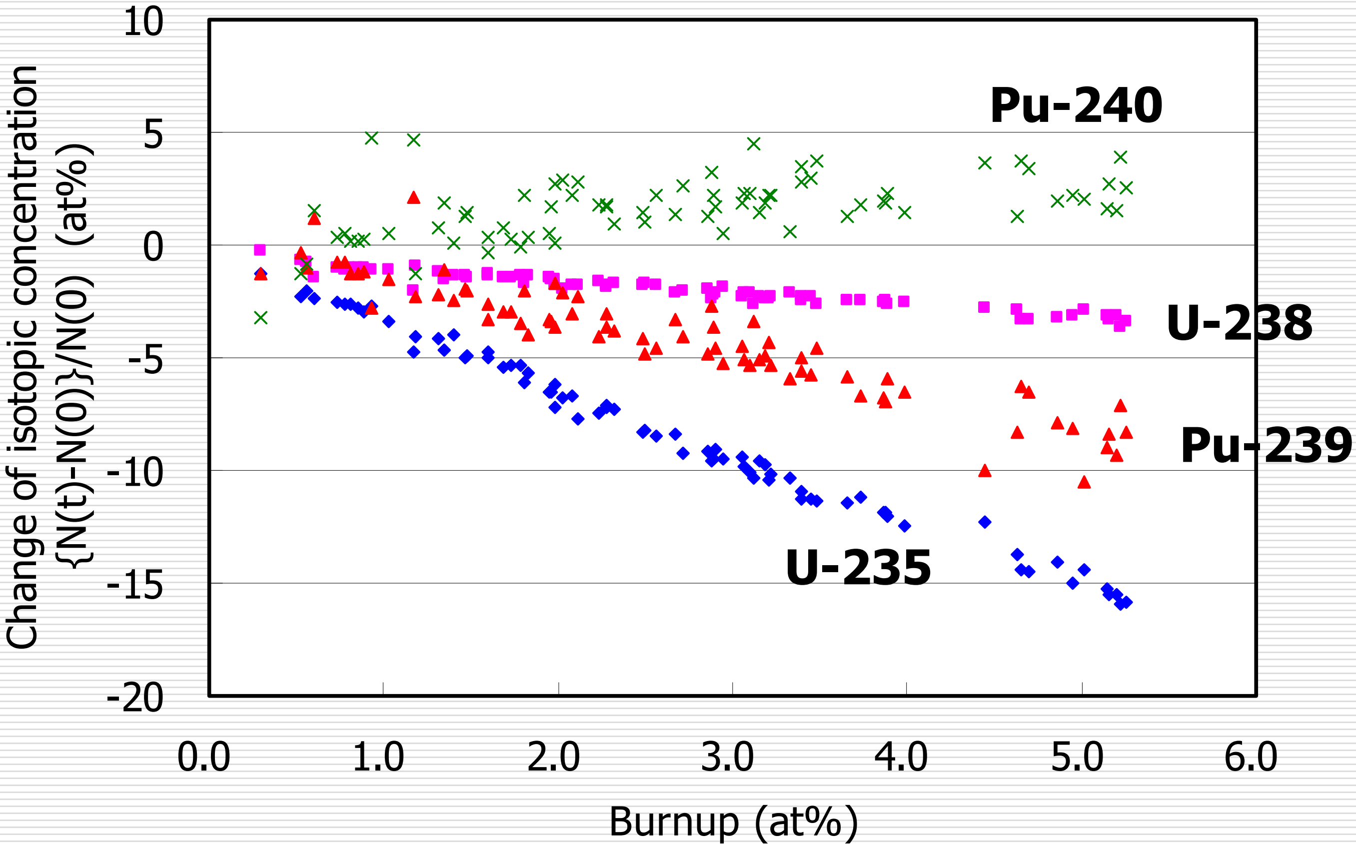
Maximum burnup: about 5 at%

Number of PIE specimens: about 70



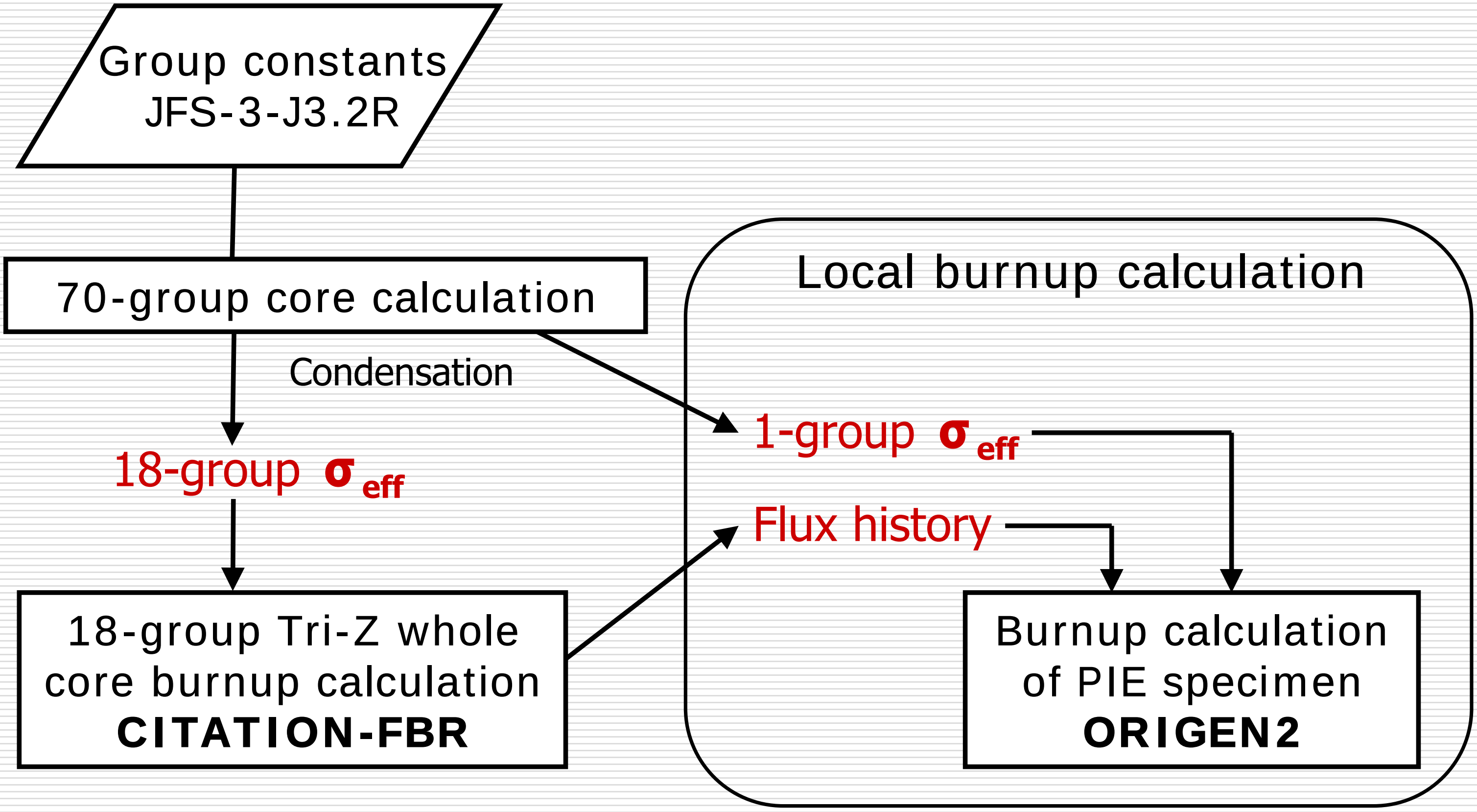
JOYO MK-I core and the examined fuel positions

JOYO MK-I driver fuel
PIE Result of isotopic concentration change



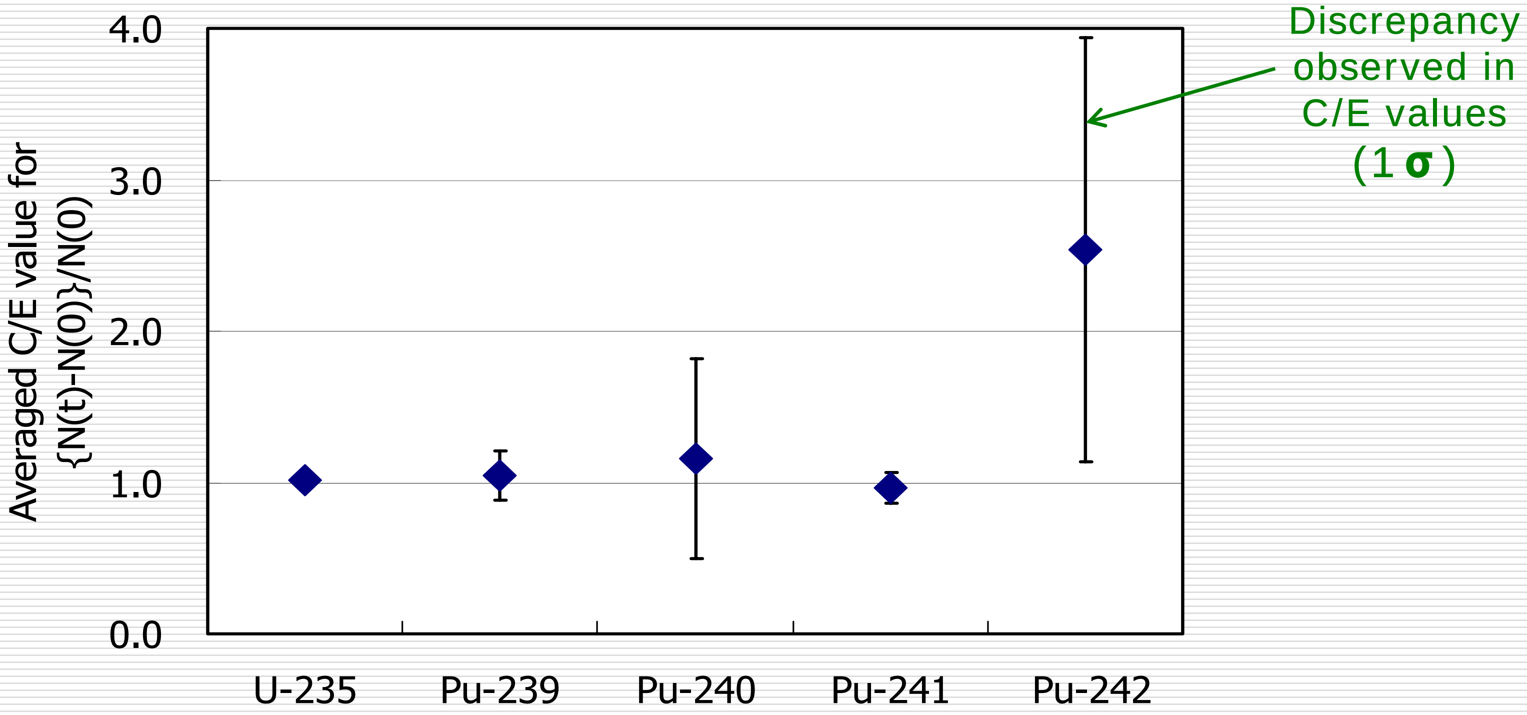
JOYO MK-I driver fuel

Method of calculation



JOYO MK-I driver fuel

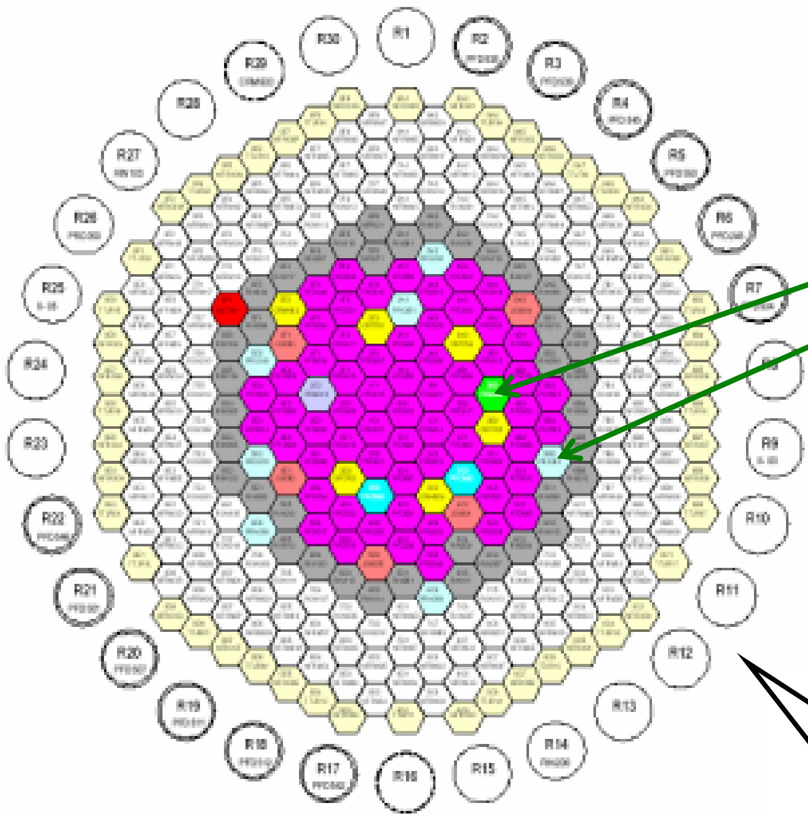
Result of PIE analysis



◆ PIE data have large discrepancy for minority isotopes.

⇨ We have moved to MK-II PIE where refined analytical technique was applied.

IV Progress in PIE analysis (2) - MA sample irradiation -



JOYO MK-II core (32nd cycle)

Np-237, Am-241, Am-243, Cm-244 (25 specimens)

Irradiation positions

3rd row, 208 efpd (29th-32nd cycle)

5th row, 251 efpd (30th-33rd cycle)

Irradiation was started in August '94.

⇩

The first PIE (^{243}Am) was finished in October, 2003.

3rd row, Z=+350 mm (in reflector)

- MK-II driver fuel
- Control rod
- Irradiation test S/A
- Inner reflector

MA sample irradiation

Analysis of the first Am-243 sample

Initial composition: Am-241/Am-243 = 12.2/87.8 (at%)

We focused on

$$\frac{N_{Cm-244}(t)}{N_{Am-243}(t)} \simeq \sigma_c^{Am-243}\phi t + \cdots$$

$$\frac{N_{Am-242m}(t)}{N_{Am-241}(t)} \simeq (1 - I_\gamma)\sigma_c^{Am-241}\phi t + \cdots$$

Isomeric ratio (g/(g+m))

The daughter nuclides at the other blanch (Cm-242 and Pu-238) were not available in the first PIE.

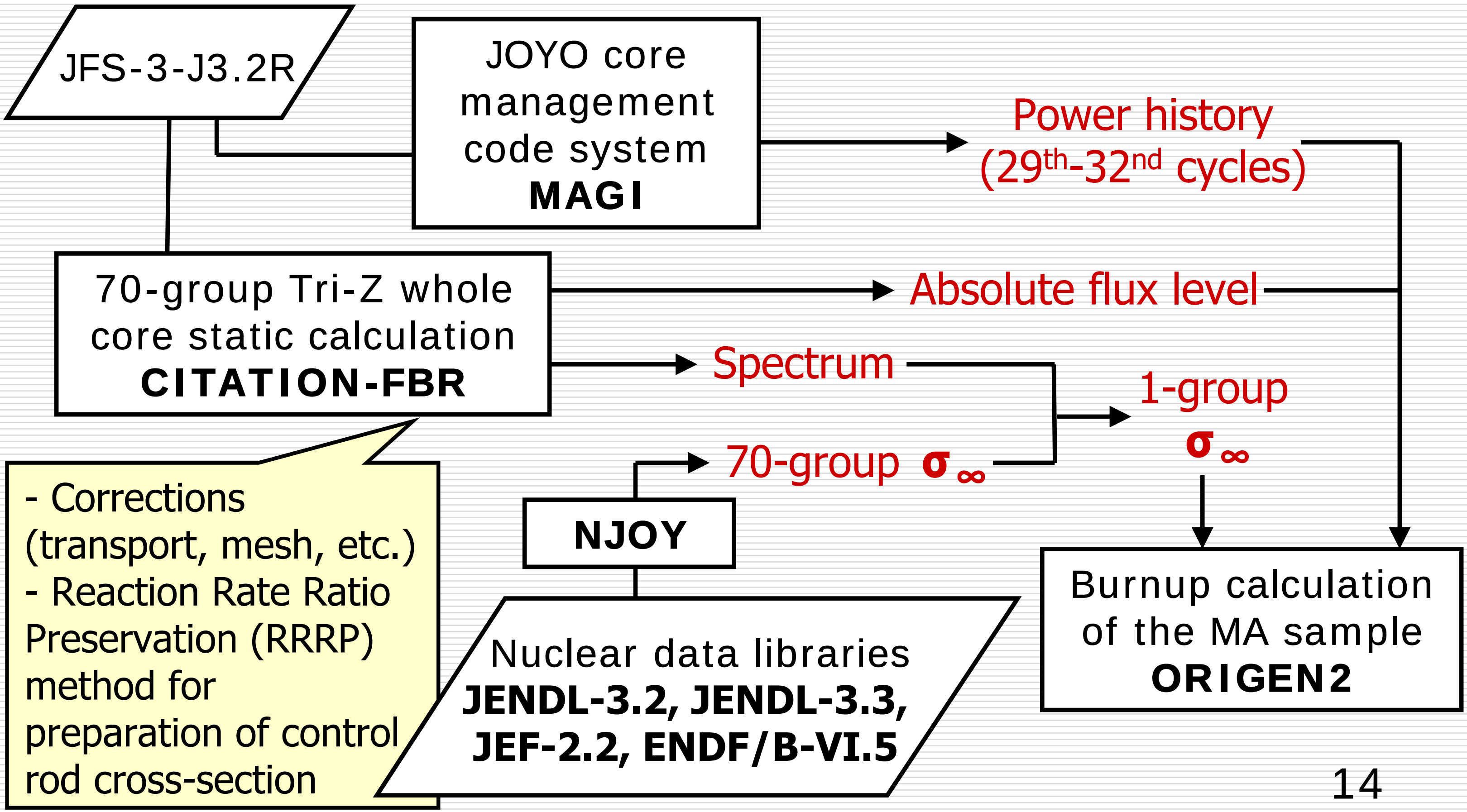
The sample loading position:

- In upper reflector region
- B_4C absorber was existing near by.

⇒ Calculation modeling error could be large.

MA sample irradiation

Method of preliminary calculation



MA sample irradiation
Preliminary C/E value

Comparison of C/E values

	PFR [Ref.1]	This work (JOYO)					PHENIX [Ref.2]
Nuclear data library	JENDL-3.2	JENDL-3.2	JENDL-3.2	JENDL-3.3	ENDF/B-VI.5	JEF-2.2	JEF-2.2
Am-241 Isomeric ratio	0.80	0.80	0.85	0.85	0.85	0.85	0.85
Cm-244 / Am-243	0.95	**0.84**	**0.84**	**0.84**	**0.83**	**0.88**	0.96
Am-242m / Am-241	1.29	**1.30**	**1.00**	**1.02**	**0.94**	**1.03**	1.03

Experimental error (1σ)
Cm-244 / Am-243: **10%** (from **α** spectroscopy)
Am-242m / Am-241: **2%** (from mass spectroscopy)

[1] K. Tsujimoto, *et al*., *Nucl. Sci. Eng*., **144**, 129 (2003).
[2] R. Soule and E. Fort, Proc. GLOBAL '97, 1332 (1997).

MA sample irradiation

Sensitivity of calculation modeling

Item	Effect on flux level	Effect on spectrum (1-group cross section) ^{241}Am capture	^{243}Am capture
Transport effect	**-5%**	-0.5%	-1%
Mesh effect	0%	0%	0%
Heterogeneity of MA loaded assembly	<0.2%	<1%	<2%
Self-shielding effect	-	～0%	～-0.1%
Control rod modeling in RRRP calculation (Model 1 vs Model 2)	0%	**-3%**	**-4%**

Model 1: Control rod surrounded by fuel.
Model 2: Control rod surrounded by reflector and fuel.

Summary

- Result of the Am-243 sample PIE
  - Satisfactory preliminary C/E values are obtained.
  - There is a possibility that Am-241 isomeric ratio is about 0.85.
  - We met the difficulty in measuring the abundance ratio of Cm/Am.
- Next to do
  - Increase the number of PIE results.
  - Perform detailed calculation (better to concentrate on the samples irradiated at the core midplane).
  - Use dosimeters for flux normalization.
  - Find MA standards for isotope dilution analysis.
  - Estimate calculation and experimental errors as realistically as possible.