

Status of the JENDL Project

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chaired by K. Nakajima, Kyoto University

Subcommittee on Nuclear Data (H.Harada, JAEA)

- ENSDF Group (H.Iimura, JAEA)
- Japanese Nuclear Data Measurement Network (Y.Watanabe, Kyushu Univ.)
- Activation Cross Section Evaluation WG (N.Iwamoto, JAEA)

Subcommittee on Reactor Constants (K. Okumura, JAEA)

- Reactor Integral Test WG (G.Chiba, Hokkaido Univ.)
- Shielding Integral Test WG (C.Konno, JAEA)
- WG on Evaluation of Nuclide Generation and Decay Heat (F. Minato, JAEA)
- Covariance Utilization WG (T.Iwasaki, Tohoku Univ.)
- Nuclear Data Processing Program WG (K.Suyama, JAEA)

Subcommittee on International Strategy (T. Fukahori, JAEA)

- International Strategy WG (K.Suyama, JAEA)

Plan of JENDL-5

- Improve reliability and completeness of data for various applications
- Revise data of light nuclei, structural material, FP, actinide
- Include all stable isotopes
- Increase covariance data
- Add isomer production data for activation

- Use new R-matrix code, AMUR, for light nucleus evaluation
- Perform evaluation with new J-PARC data (mainly for MA)
- Plan new simultaneous evaluation of fission cross section for major actinide

- To be released in FY 2021

Schedule of JENDL-5 development

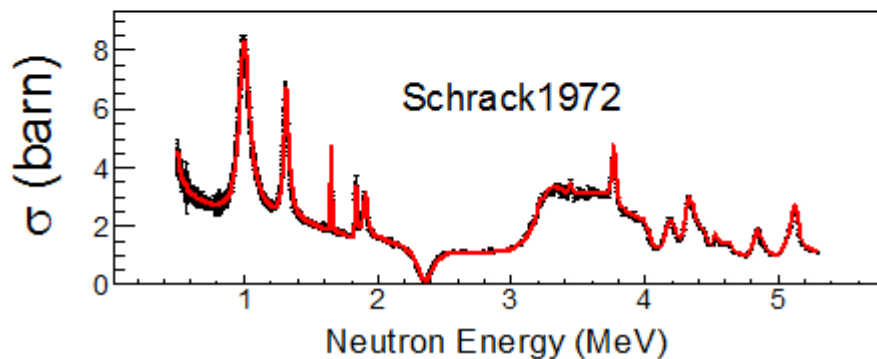
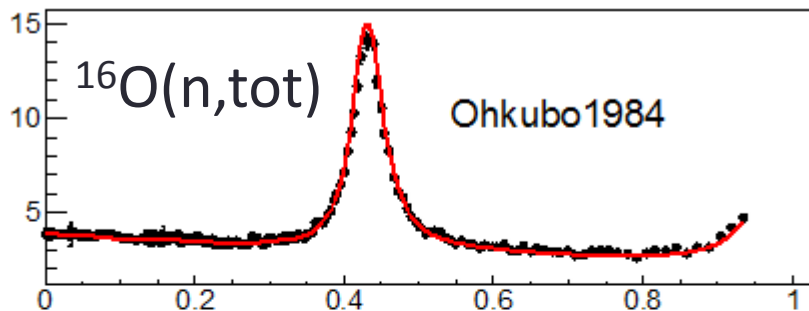
Fiscal Year	2015	2016	2017	2018	2019	2020	2021
FP	—————→				·····→		
Light nucleus	—————→					·····→	
Structure mat.	—————→					·····→	
Actinide		—————→				·····→	
Covariance				—————→			
$S(\alpha, \beta)$	—————→						
Libraries		JENDL/PD-2016 JENDL/AD-2017	JENDL-5 α		JENDL-5 β		JENDL-5

Light nucleus

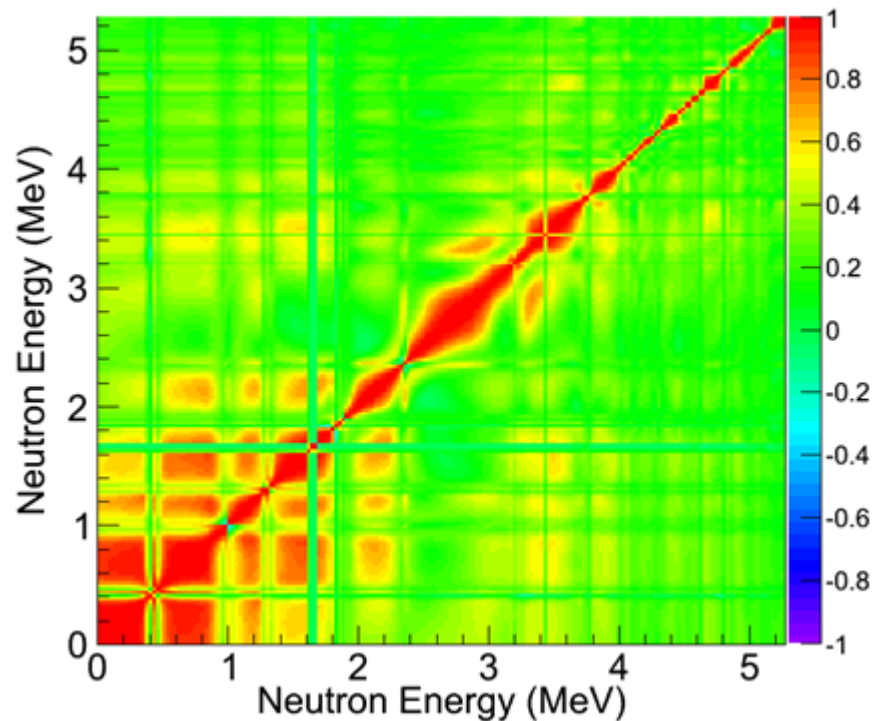
- New R-matrix code AMUR
- Preliminary evaluation of O-16, F-19
- Covariance

Analysis of ^{17}O System

Shape analysis



Correlation matrix

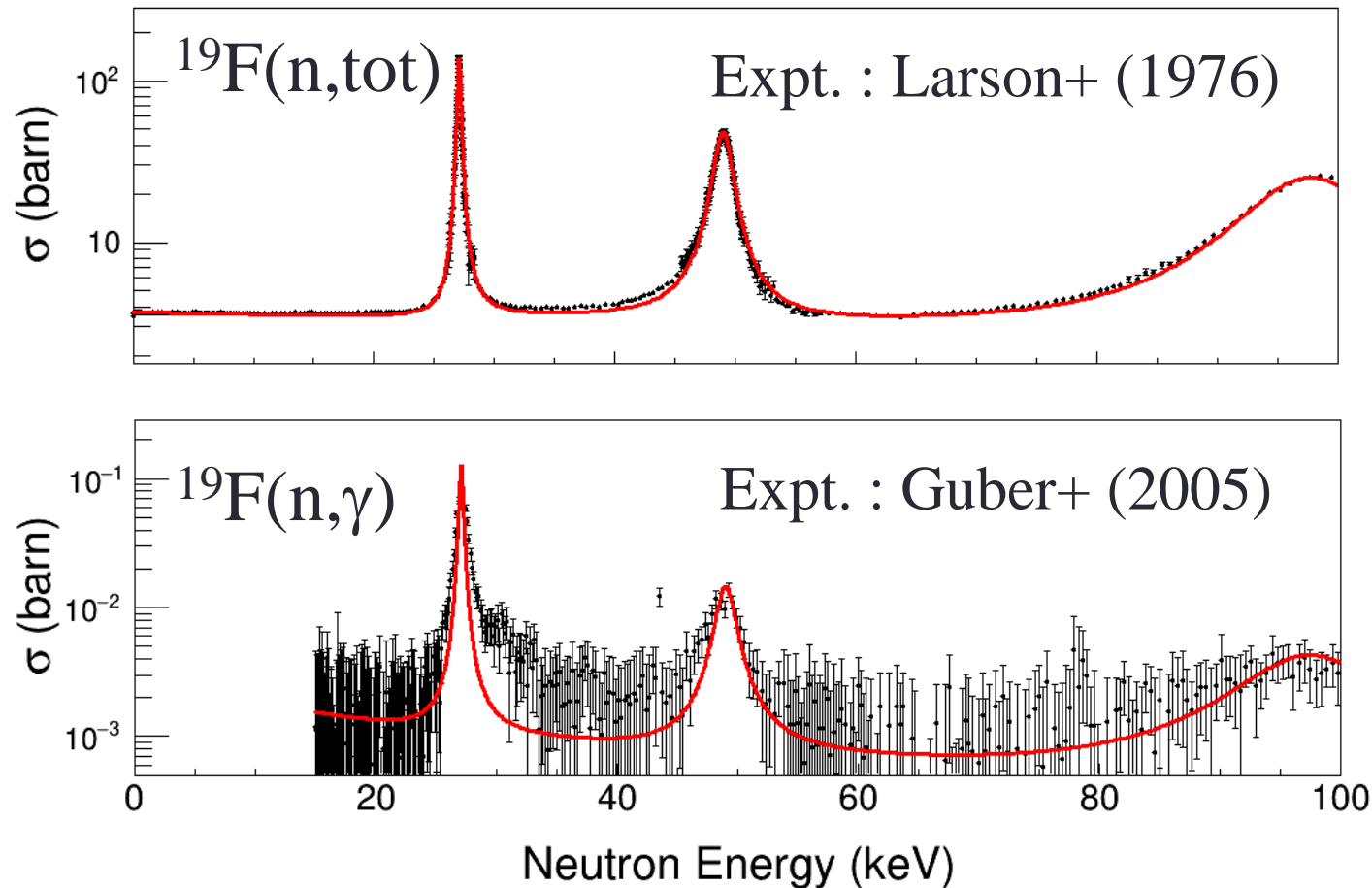


Re-normalization found to be ~ 1.0 (uncertainty $< 0.5\%$)

You can see traces of the (near) unitary limit

Analysis of ^{19}F neutron cross section Reich-Moore approximation

Preliminary result

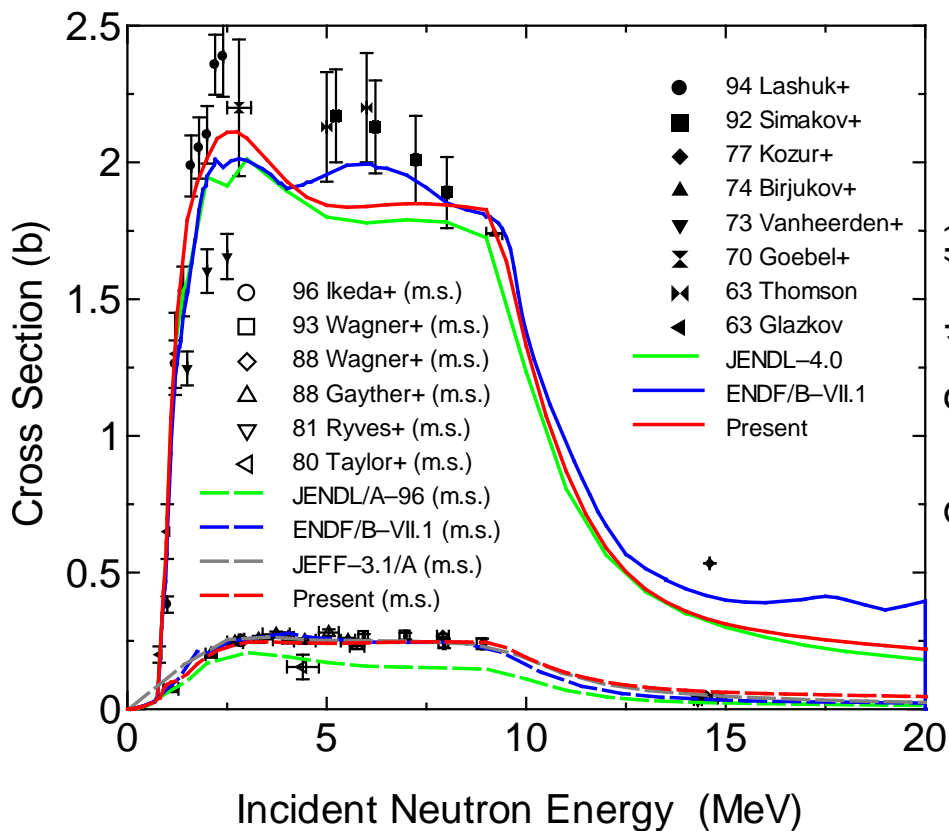


Structural material

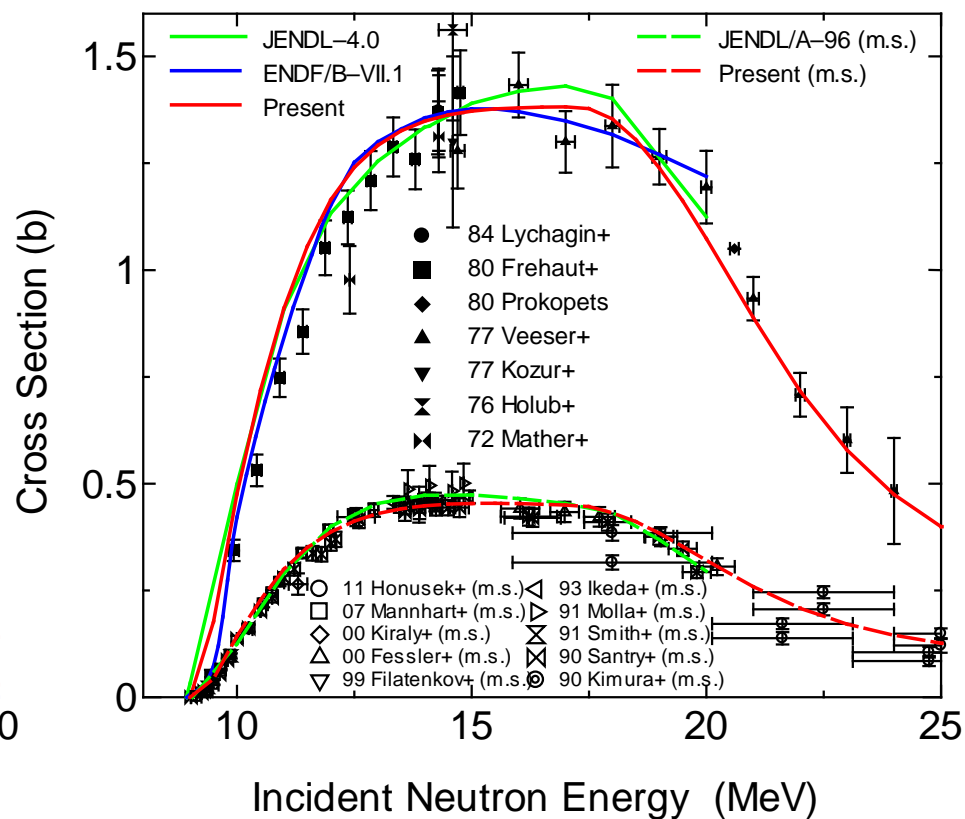
- Add isomer production data
- Update resonance parameters
- Above the resonance region
 - model calculation with CCONE
 - covariance data will be evaluated CCONE + KALMAN

Evaluation of Nb

$^{93}\text{Nb} (n,n')$

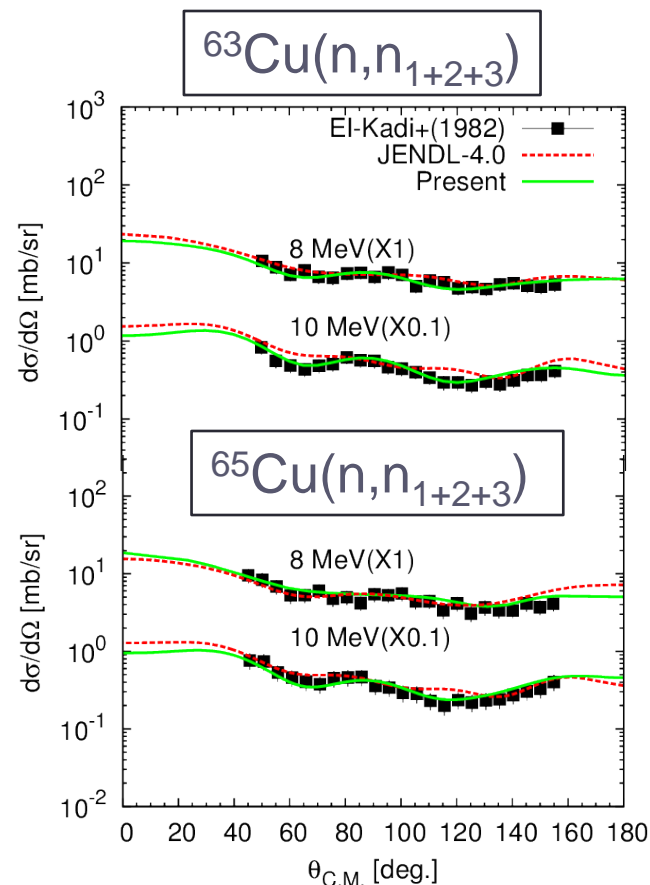
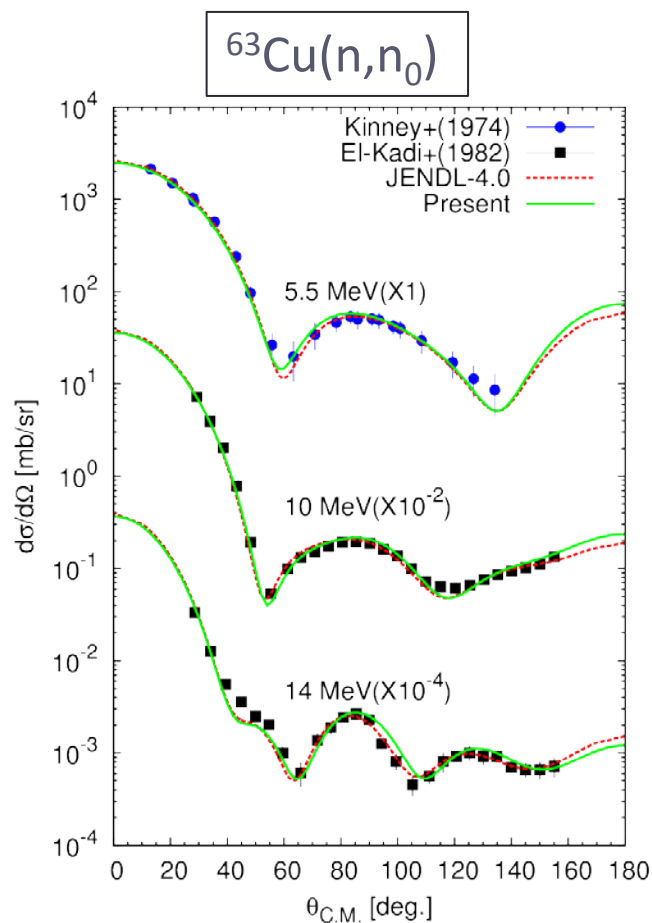


$^{93}\text{Nb} (n,2n)$

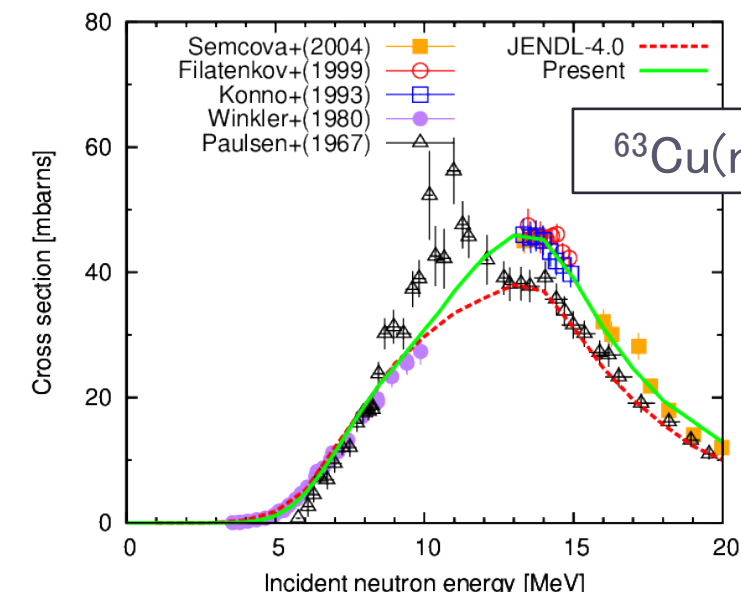
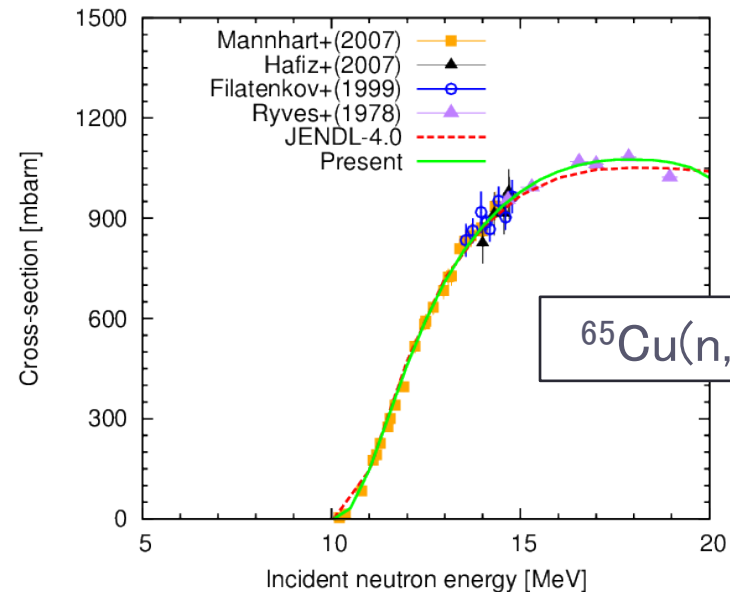
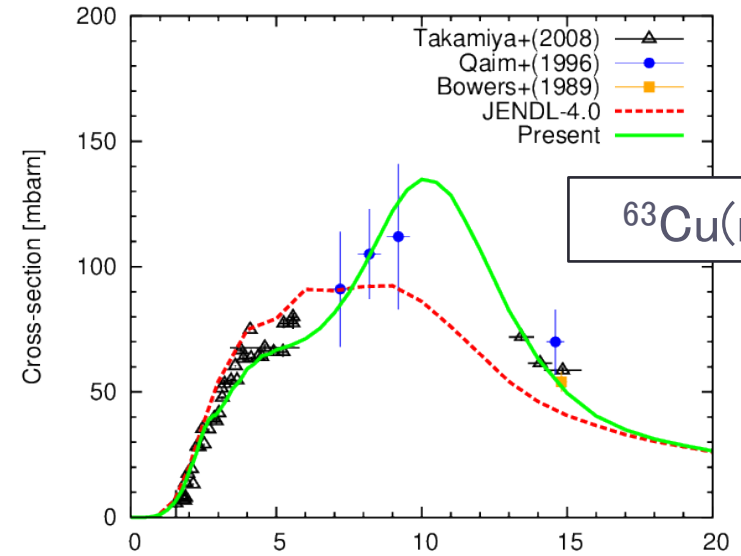
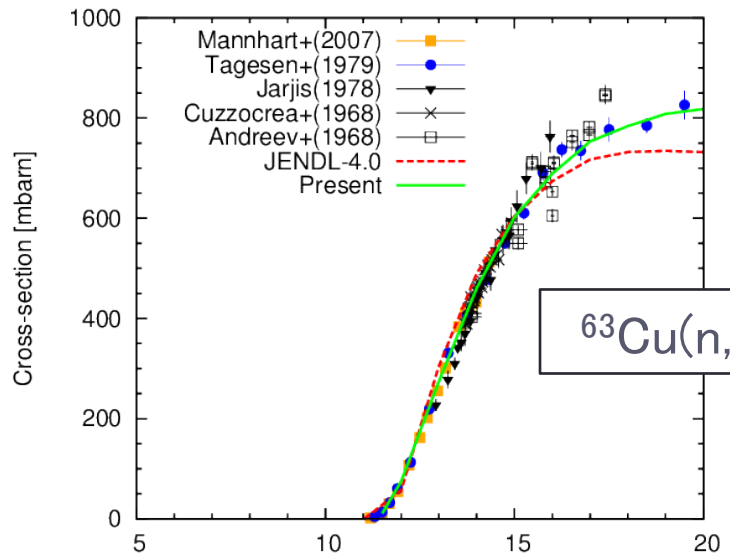


Evaluation of Cu isotopes

Elastic and inelastic scattering angular distribution



Various reaction cross sections on Cu

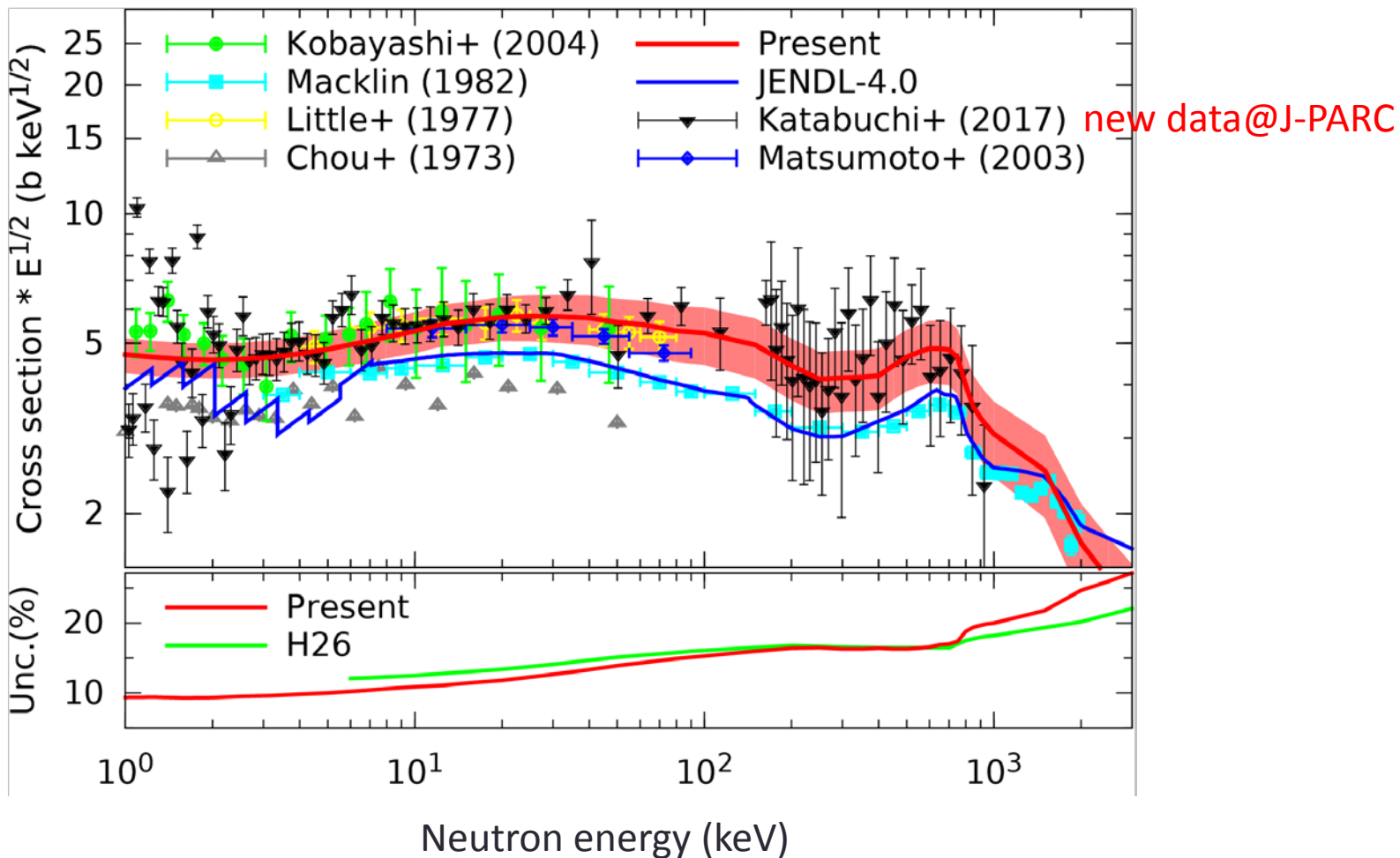


Fission products and medium heavy nuclides

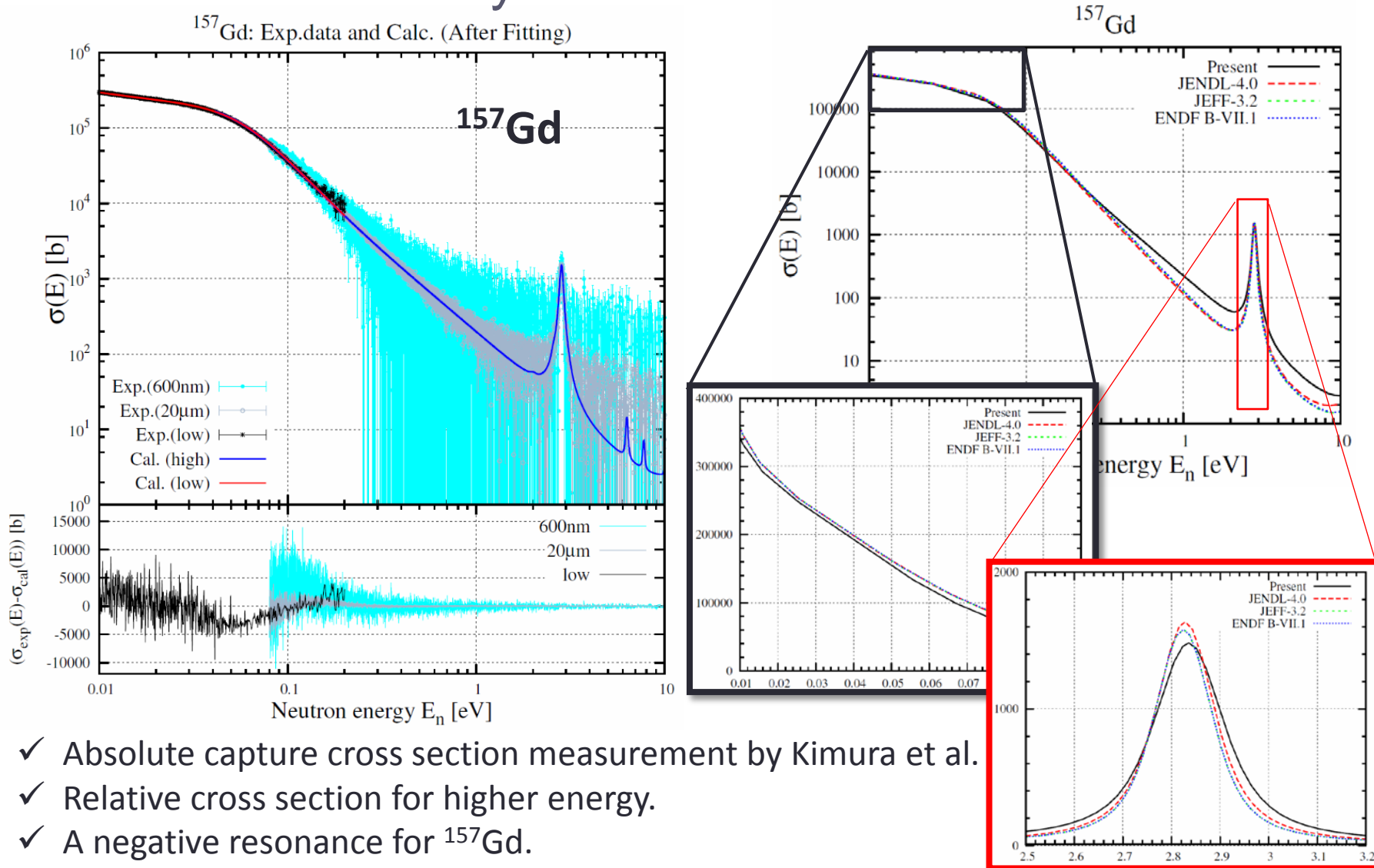
- Objectives
 - Updating old FP evaluations
 - Providing activation cross sections for decommissioning of LWRs
- Evaluated nuclides
 - Ga, Nb, Tc, Sb, Te, I, Er
 - Ta, Pt, Hg, Tl
 - Most of them have already published from JNST.
- Evaluations with new experimental data at J-PARC are in progress.

Evaluation of ^{99}Tc

^{99}Tc neutron capture cross section



Resonance analysis of capture cross section of Gd measured by J-PARC ANNRI



- ✓ Absolute capture cross section measurement by Kimura et al.
- ✓ Relative cross section for higher energy.
- ✓ A negative resonance for ¹⁵⁷Gd.

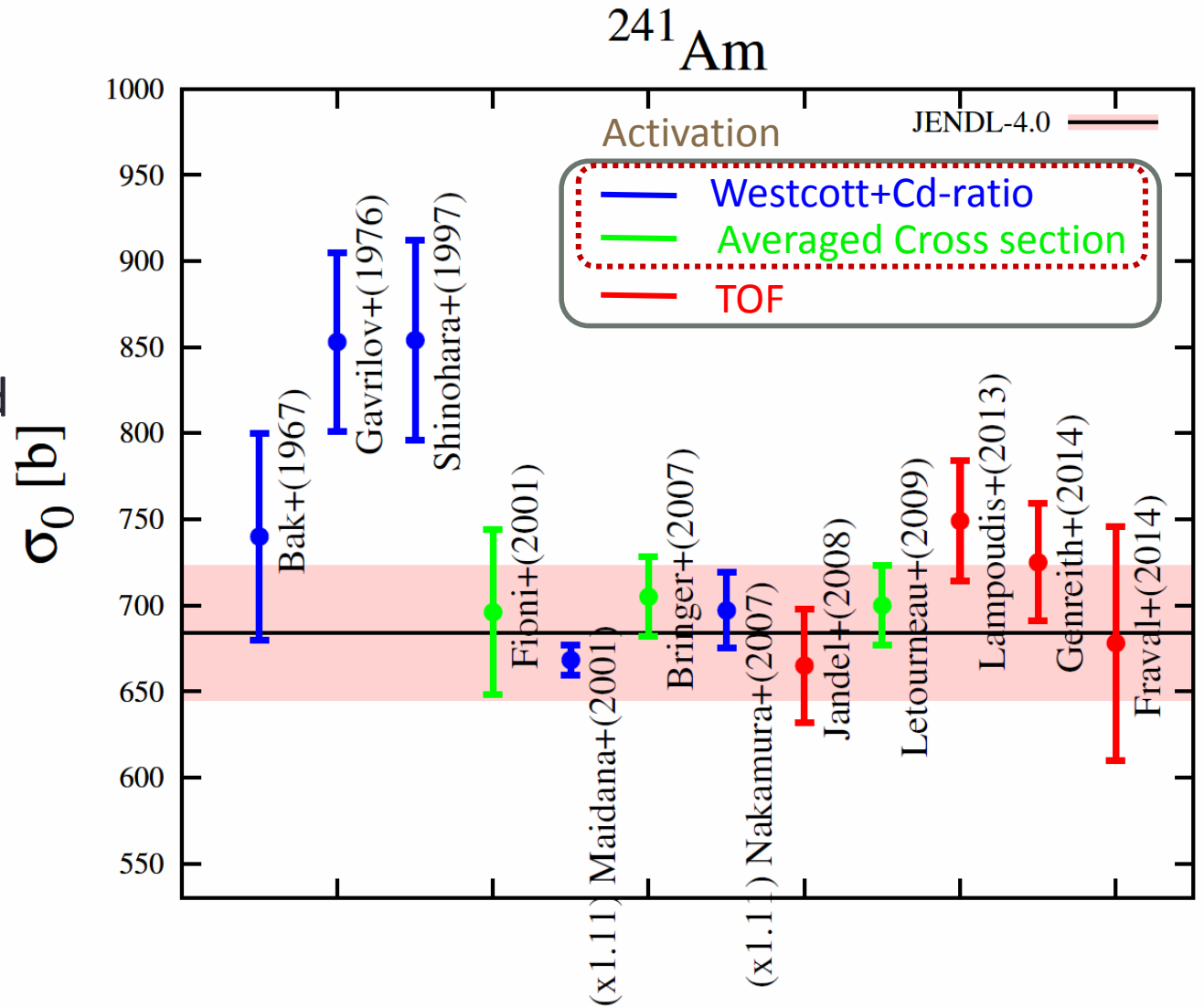
Actinides

- Minor actinides such as Am-241, 243, Np-237 will be updated using new experimental data of J-PARC.
- Activation cross section data of MA were revisited.
- Simultaneous evaluation for fission cross section of major actinides is planned.

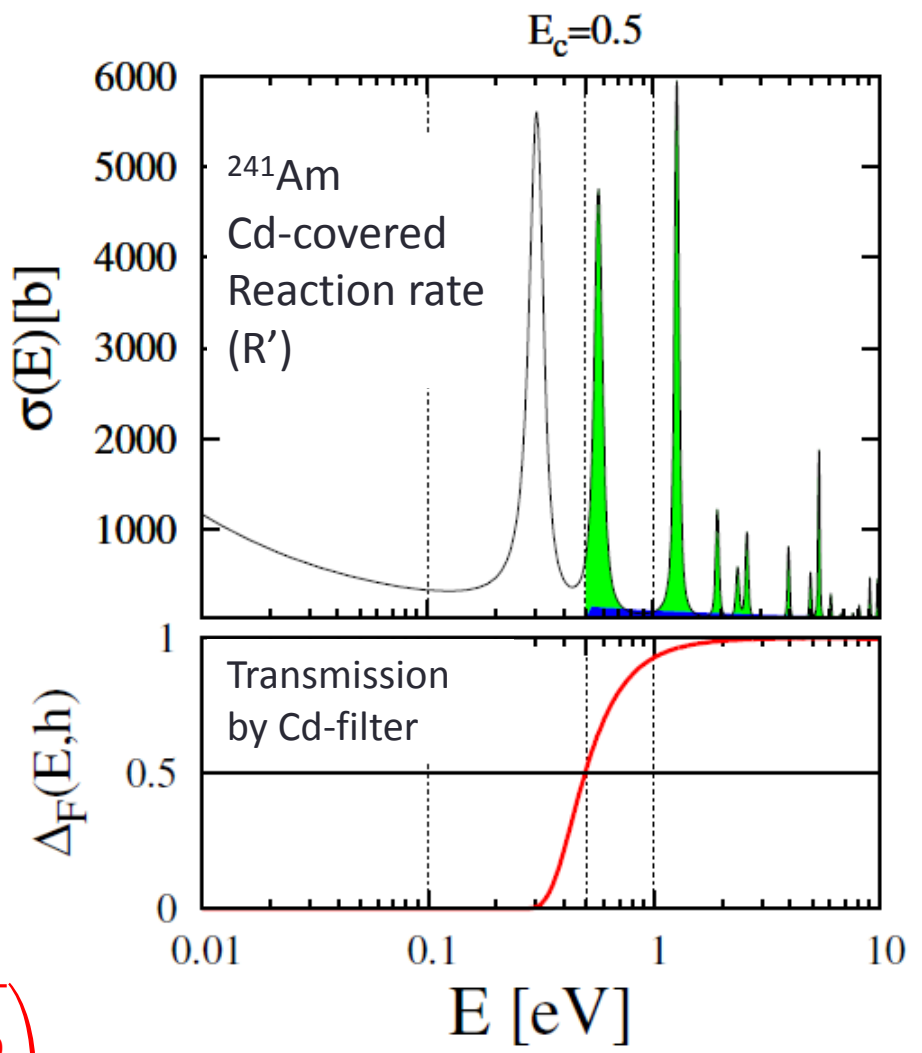
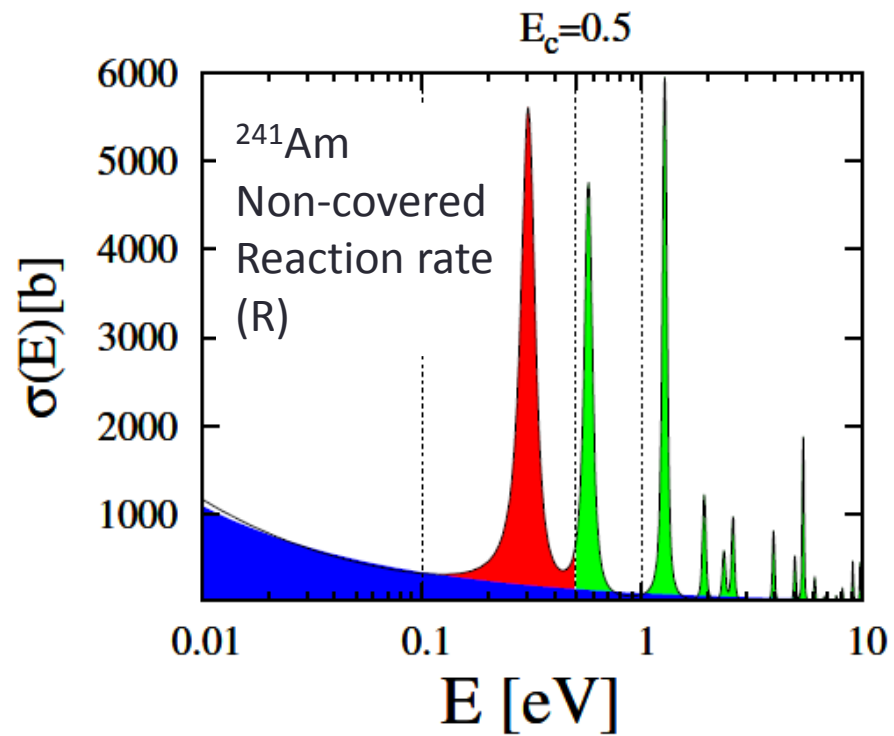
Current status of the thermal neutron capture cross section of MAs (e.g. ^{241}Am)

✓ Large discrepancy among the reported data of MAs.

✓ The data measured by **activation** were overestimated maximally by 20% from JENDL-4.0.



Correction of Westcott convention for MAs



$$R/\sigma_0 = g\phi_1 + s_0^c\phi_2 + \delta s_0\phi_2$$

$$R'/\sigma_0 = g\phi_1' + s_0^c\phi_2'$$

$$\delta s_0 = \frac{2}{\sigma_0\sqrt{\pi}} \int_{\mu kT}^{E_c} \frac{dE}{E} \left(\sigma(E) - g\sigma_0 \sqrt{\frac{E_0}{E}} \right)$$

Corrected thermal capture cross section for

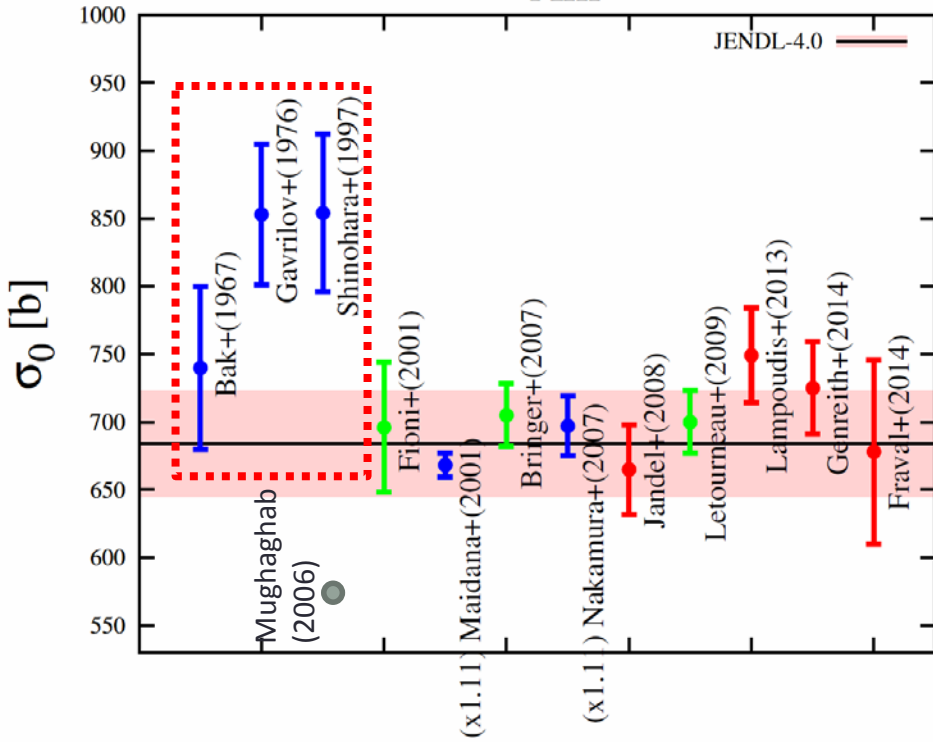
²⁴¹Am

Activation

- Westcott+Cd-ratio
- Averaged Cross section
- TOF

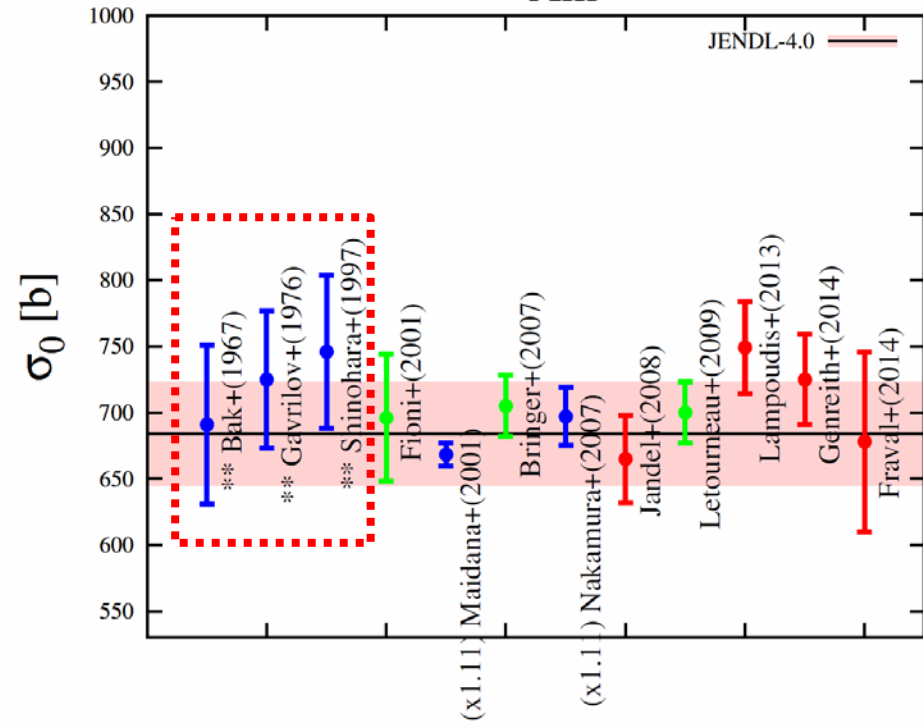
Before correction

²⁴¹Am



After correction

²⁴¹Am



Discrepancy among the data became smaller.

Summary of nuclear data evaluation

- JENDL-5 is under development.
- Evaluations for light nuclei, structure materials, fission products, and actinides are in progress.
- CIELO data will be tested with JENDL.
- Thermal scattering law data of H₂O will be updated in cooperation with Kyoto Univ.
- JENDL-5 will be released in FY 2021.

Development of nuclear data processing system FRENDY

- JAEA started developing a new nuclear data processing system FRENDY in 2013
 - **FR**om **E**valuated **N**uclear **D**ata librar**Y** to any application
 - To process the nuclear data library by JAEA's nuclear application codes users
- The first goal is processing the nuclear data for continuous energy Monte Carlo codes
 - For MVP, PHITS of JAEA and MCNP of LANL

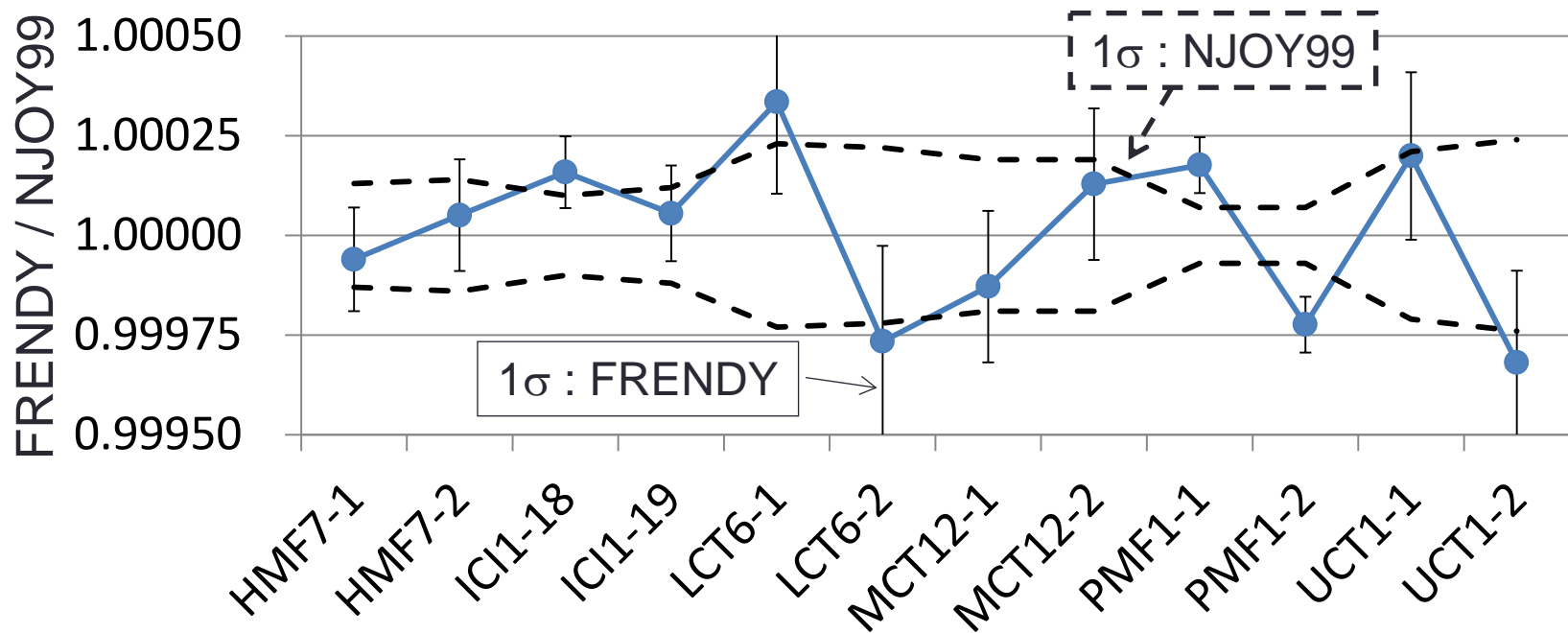


Features of FRENDY

- Utilization of modern programming techniques
 - C++, BoostTest library, Git
 - Improvement of quality and reliability
- **Consideration of maintainability, modularity, portability and flexibility**
 - Encapsulate all classes
 - Minimize the function
 - Maintain the independence of each module
- **Processing methods of FRENDY is similar to NJOY99**
 - The modification of the processing methods and implementation of the original functions will be investigated in the future
- **Reflecting requests of nuclear data processing system users**
 - Development of FRENDY is supported by many organizations and companies in Japan

Comparison for integral experiments

- k_{eff} values of ICSBEP benchmark are compared
 - MCNP sample input files in ICSBEP hand book are used
- k_{eff} values of FRENDY are similar to that of NJOY99
 - Differences are not so varied with the neutron spectra and the major fissile materials
- FRENDY properly generates ACE files



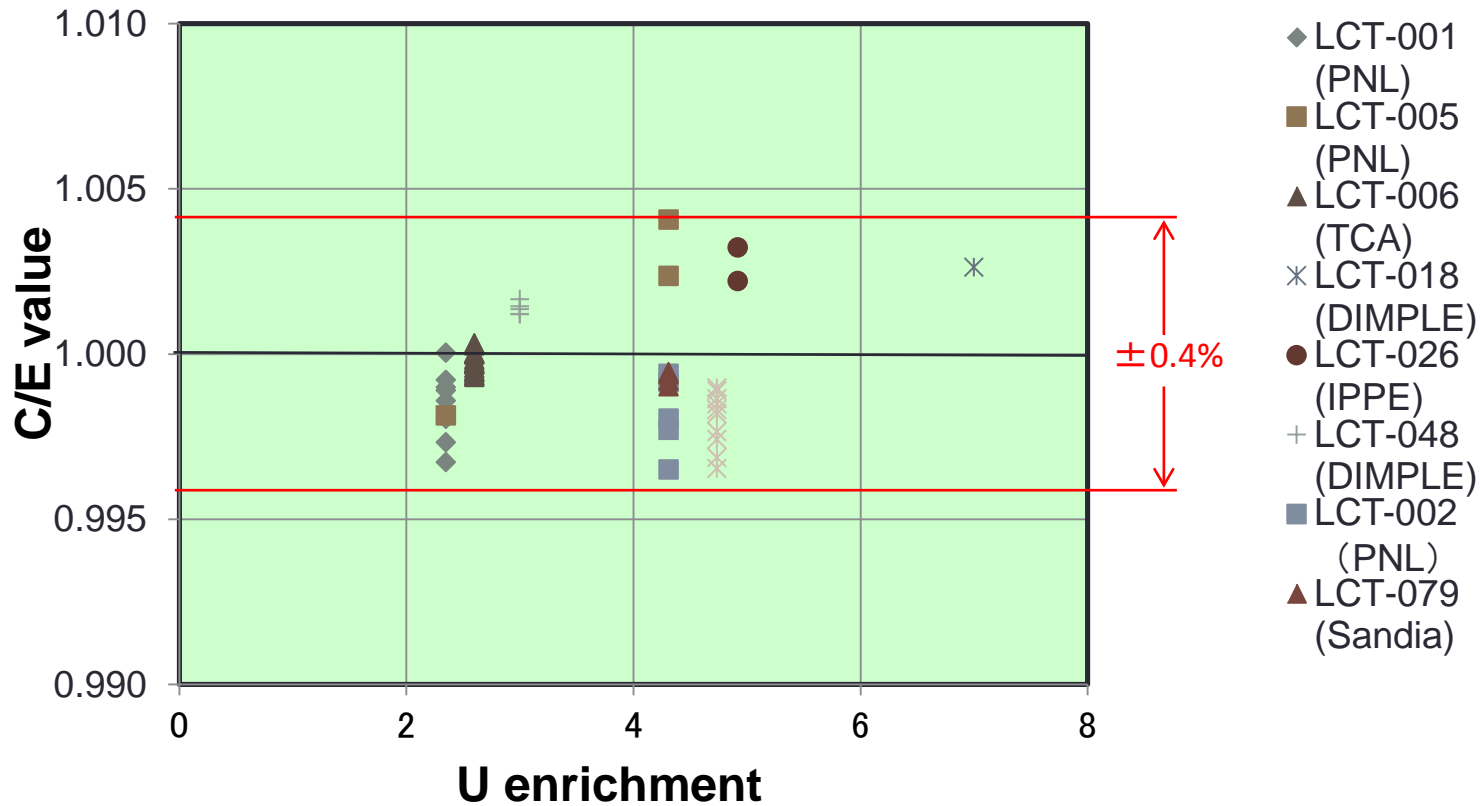
Benchmarking toward Next JENDL

- The 1st phase task of RIT-WG (Reactor Integral Test Working Group) in JENDL committee has been completed
 - Development of a comprehensive and ready-to-use standard benchmark set, based on Japanese Monte-Carlo code MVP, for LWR nuclear data by utilizing open and well-evaluated integral experiments, such as ICSBEP and IRPhEP (NEA-DBs)
- New thick (152 pages) report was written up
 - RIT-WG, “Compilation of the Data Book on Light Water Reactor Benchmark to Develop the Next Version of JENDL – Utilization of Criticality Data in ICSBEP and IRPhEP Open Databases,” JAEA-Data/Code 2017-006 (2017) [in Japanese]
 - Two benchmark sets are recommended in the report
 1. Light-water-moderated low-enriched U cores in NEA-DBs
 2. Light-water-moderated MOX cores in NEA-DBs

Recommended Benchmark Set for Light-water-moderated Low-enriched U cores

No.	Objectives of Benchmark	Series of Experiments	Case Number	Comments
1	U-235, U-238 Basic Benchmarks Dependencies on - U enrichment - H/U atomic number ratio - Fuel pin pitch - Number of fuel pins	LCT-001 (PNL)	1~8	U enrichment: 2.35wt%
		LCT-005 (PNL)	1, 5, 14	U enrichment: 2.35, 4.31wt%
		LCT-006 (TCA)	1~18	U enrichment: 2.60wt%
		LCT-048 (DIMPLE)	1~5	U enrichment: 3.01wt%
		LGT-002 (PNL)	1~5	U enrichment: 4.31wt%
		LCT-079 (Sandia)	1, 2, 6, 7	U enrichment: 4.31wt%
		LCT-007 (Vulduc)	1~10	U enrichment: 4.74wt%
		LCT-026 (IPPE)	1, 3	U enrichment: 4.92wt%
	LCT-018 (DIMPLE)	1	U enrichment: 7.00wt%	
Total: 56 data				
2	Dependency on Boron concentration (Room temperature)	LCT-008 (B&W)	1~17	Boron concentration: 779~1511ppm
		KRITZ-2:1	1	Boron concentration: 218ppm
		KRITZ-2:13	1	Boron concentration: 452ppm
Total: 19 data				
3	Dependency on Gd concentration	LCT-005 (PNL)	1~11, 14	Gd concentration: 0~1.48g Gd/L
Total: 12 data				
4	Dependency on Rh inventory	LCT-079 (Sandia)	1~10	Rh foil thickness(31 sheets): 0~100 μm
Total: 10 data				
5	Dependency on core temperature	LCT-026 (IPPE)	1~4	Core temperature: 20, 231, 19, 206°C
		KRITZ-2:1	1~2	Core temperature: 20, 249°C
		KRITZ-2:13	1~2	Core temperature: 22, 280°C
Total: 8 data				
6	Reflector effect (Pb)	LCT-010 (PNL)	1~4, 20~23	U enrichment: 4.31wt%
		LCT-017 (PNL)	1~3, 23~25	U enrichment: 2.35wt%
Total: 14 data				
7	Reflector effect (Depleted U)	LCT-010 (PNL)	5, 7~8, 24~30	U enrichment: 4.31wt%
		LCT-017 (PNL)	4~9, 26~29	U enrichment: 2.35wt%
Total: 20 data				
8	Reflector effect (Fe)	LCT-010 (PNL)	9~19	U enrichment: 4.31wt%
		LCT-017 (PNL)	10~22	U enrichment: 2.35wt%
Total: 24 data				
9	Unrecommended for benchmarking	LCT-005 (PNL)	12, 13, 16	Fuel pin pitch: 1.598cm
		LCT-005 (PNL)	15	Outliner of C/E by JENDL-4.0
		LCT-010 (PNL)	6	Outliner of C/E by JENDL-4.0
		LCT-019 (Kurchatov)	1~3	Outliner of C/E by JENDL-4.0
		LCT-022 (Kurchatov)	1~7	Outliner of C/E by JENDL-4.0
		LCT-024 (Kurchatov)	1~2	Outliner of C/E by JENDL-4.0
	LCT-025 (Kurchatov)	1~4	Outliner of C/E by JENDL-4.0	
Total: 21 data				

Result of Recommended Benchmark Set for Light-water-moderated Low-enriched U cores



**Fig. Dependency on U enrichment for Criticality
(Benchmark Set No.1 with 56 data)**

- Experiments using neutron absorbers and FPs (i.e., B, Gd, and Rh) are excluded
- Only cores with H₂O (not Pb, Depleted U, or Fe) reflectors in room temperature are selected
- 18 data judged as outliers by the trend of C/E values are excluded

Recommended Benchmark Set for Light-water-moderated MOX cores

No.	Objectives of Benchmark	Series of Experiments	Case Number	Comments
1	Pu, U-238 basic benchmarks Dependencies on - Pu enrichment - H/Pu atomic number ratio - Fuel pin pitch - Number of fuel pins	KRITZ-2:19 (Studsvik)	1	Pu enrichment: 1.5wt%, Pu240: 7.8at%
		MCT-009 (CAF)	2~6	Pu enrichment: 1.5wt%, Pu240: 7.8at%
		MCT-002 (PRCF)	1, 3, 5	Pu enrichment: 2.0wt%, Pu240: 7.7at%
		MCT-006 (CAF)	1~6	Pu enrichment: 2.0wt%, Pu240: 7.7at%
		MCT-007 (CAF)	1~5	Pu enrichment: 2.0wt%, Pu240: 16.5at%
		MCT-008 (CAF)	1~6	Pu enrichment: 2.0wt%, Pu240: 23.4at%
		MCT-004 (TCA)	1~11	Pu enrichment: 3.0wt% (low density), Pu240: 22.0at%
		MCT-005 (CAF)	1, 2, 4~7	Pu enrichment: 4.0wt%, Pu240: 18.1at%
		MCT-003 (CRX)	1, 2, 4~6	Pu enrichment: 6.6wt%, Pu240: 8.5at%
		MCT-001 (CML)	1~4	Pu enrichment: 22.3wt%, Pu240: 11.4at%
		MCT011 (Valduc)	1~6	Pu enrichment: 25.6wt%, Pu240: 9.7at%
Total: 58 data				
2	Dependency on Boron concentration	MCT-002 (PRCF)	1~6	Boron concentration: 688~1090ppm
		MCT-003 (CRX)	2, 3	Boron concentration: 337ppm
Total: 8 data				
3	Dependency on core temperature	KRITZ-2:19 (Studsvik)	1~2	Core temperature: 21, 236°C
		Total: 2 data		
4	Unrecommended for benchmarking	MCT-009 (CAF)	1	Outliner of C/E by JENDL-4.0
		MCT-005 (CAF)	3	Outliner of C/E by JENDL-4.0
Total: 2 data				

Result of Recommended Benchmark Set for Light-water-moderated MOX cores

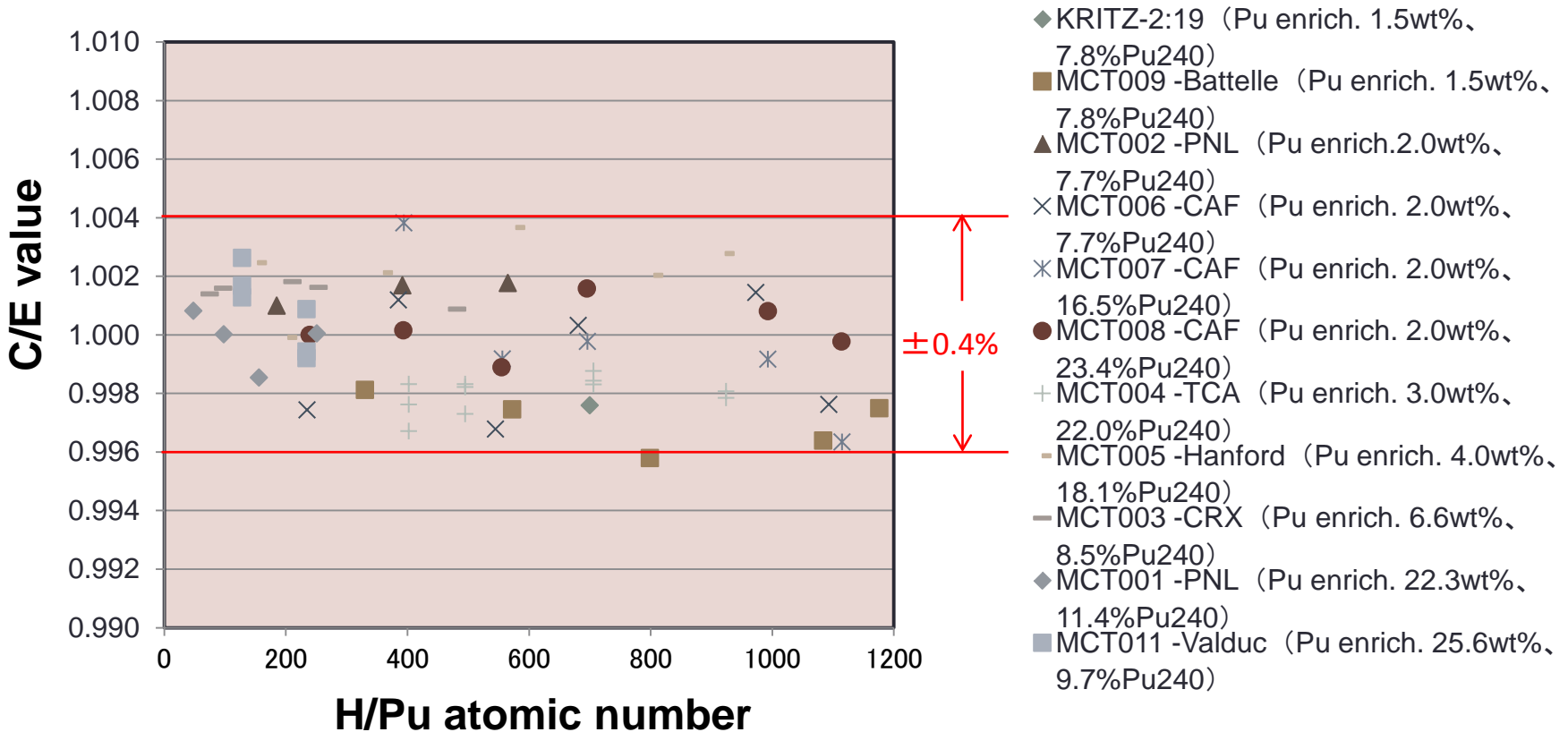
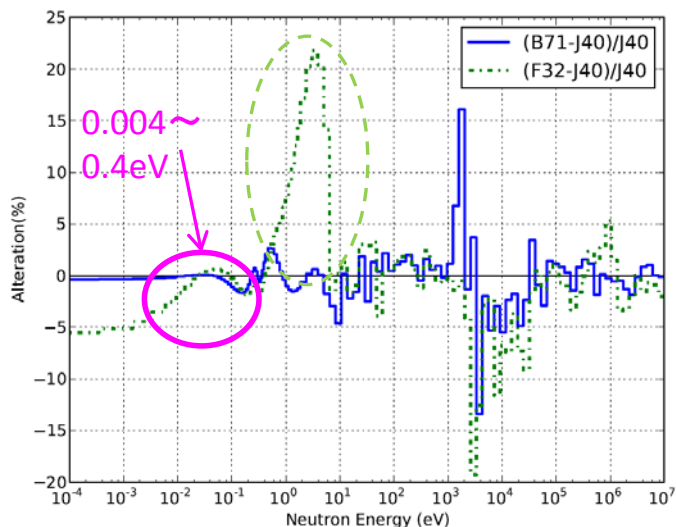


Fig. Dependency on H/Pu atomic number ratio for Criticality (Benchmark Set No.1 with 58 data)

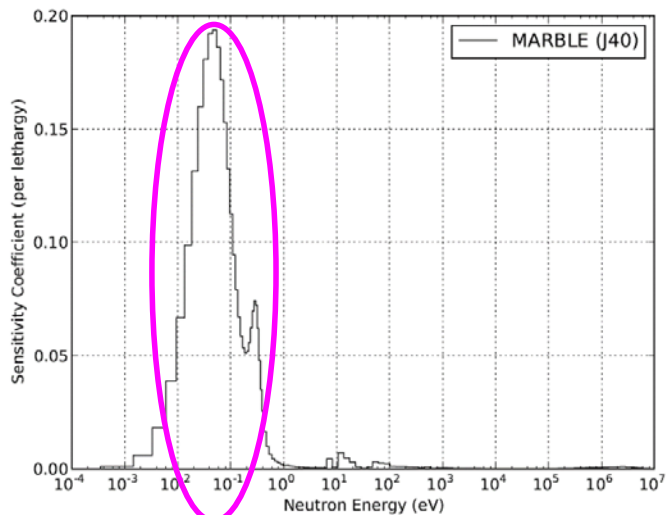
- Experiments using a large amount of Boron are excluded
- Cores with high temperature H₂O moderator are excluded
- 2 data judged as outliers by the trend of C/E values are excluded

Cross Section Alteration Pu-239 fission



(a) Differences of Pu-239 fission cross section compared with ENDF/B-VII.1 and

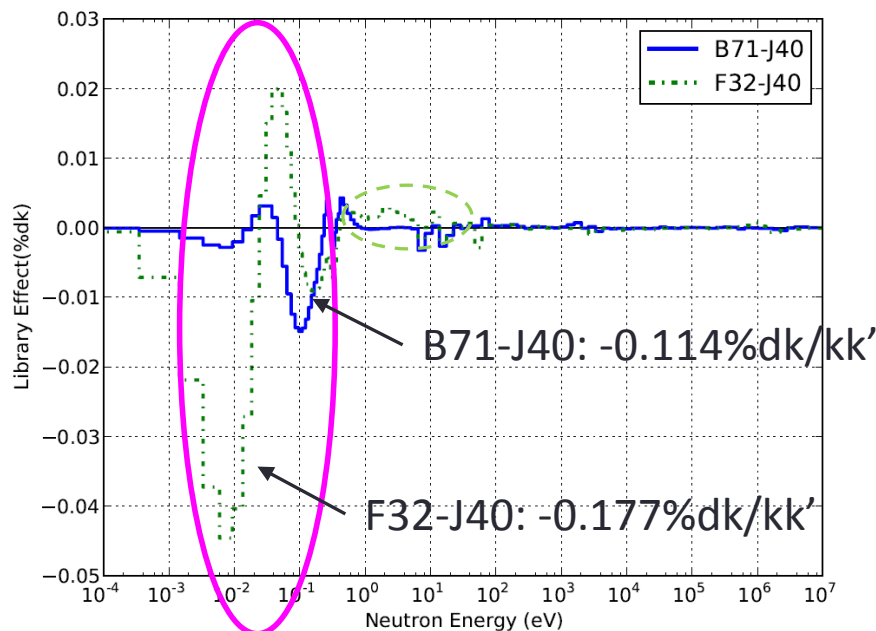
Pu-239 fission (MCT009_case6, KEFF)



(b) Sensitivity coefficient of Pu-239 fission for MCT-009_case6

Example of Sensitivity Analysis

Library Effect (MCT009_case6) Pu-239 fission

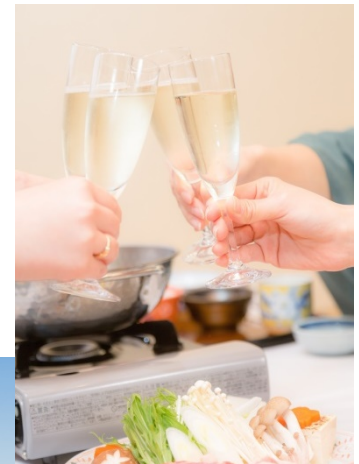


(c) Contribution of Pu-239 fission to criticality of MCT-009_case6

- Sensitivity analysis has been started by using the recommended benchmark set
- Big difference of nuclear data does not always affect the integral parameters
- It is very useful to determine the important energy regions and reactions

Development of automatic nuclear data validation system VACANCE

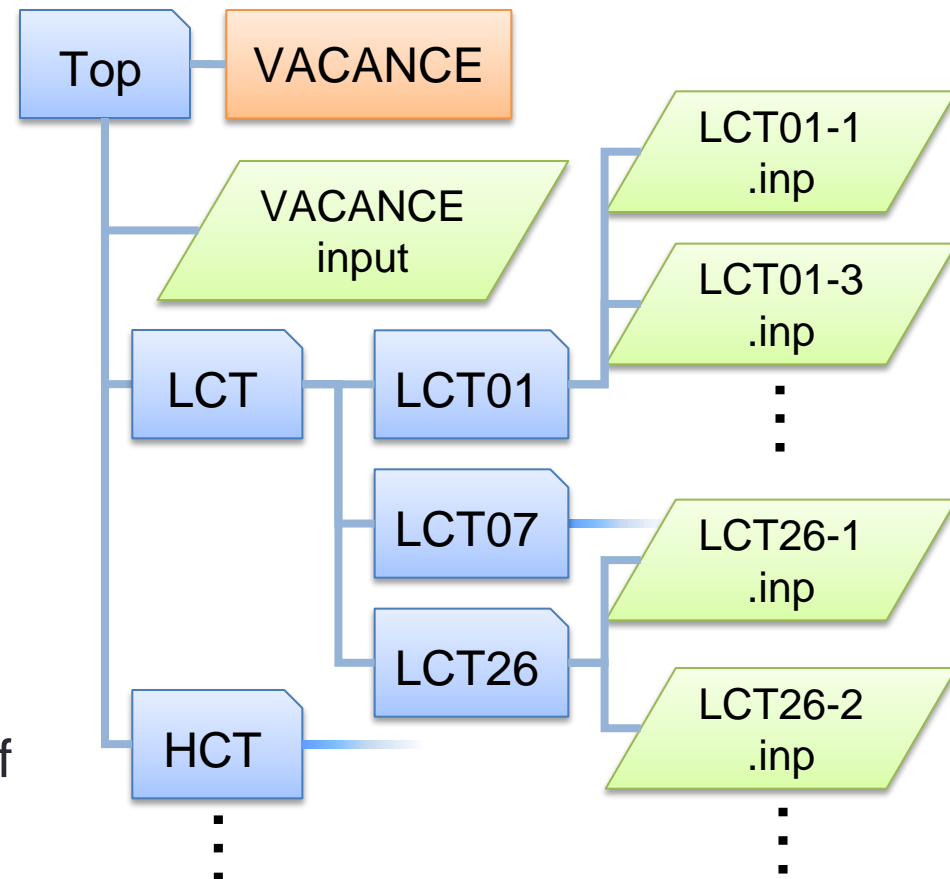
- JAEA started developing an automatic nuclear data validation system **VACANCE** in 2016
 - **V**alidation Environment for **C**omprehensive and **A**utomatic **N**eutronics **C**alculation **E**xecution
- VACANCE significantly reduces workload and human error
 - Automatically runs nuclear data validation cycle



Characteristics of VACANCE (1/2)

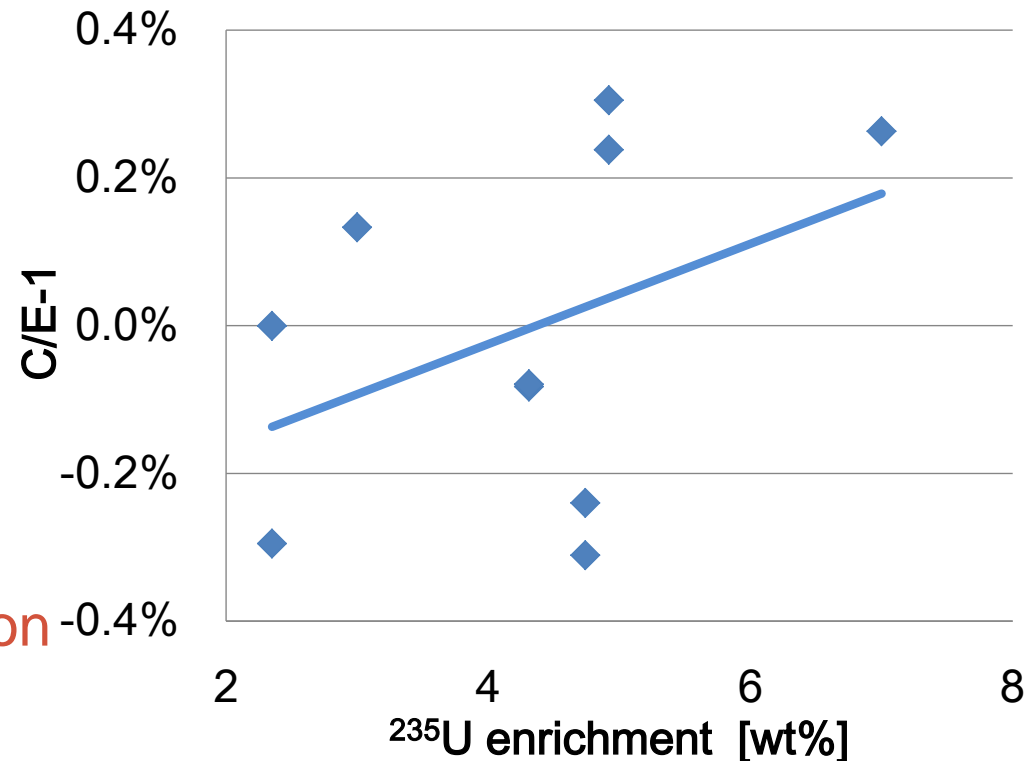
- Automatic input file search
 - VACANCE automatically searches all input files in the user specified directory
- Automatic input file modification
 - To easily change the input option and nuclear data library
 - Number of history, batch size, flux output option, ...
 - JENDL → ENDF, JEFF, TENDL, ...
- Enables a parallel computation using OpenMP
 - To efficiently run the hundreds of calculations
- Enable restart calculation

【 Example of directory structure of integral experiment calculations using VACANCE 】



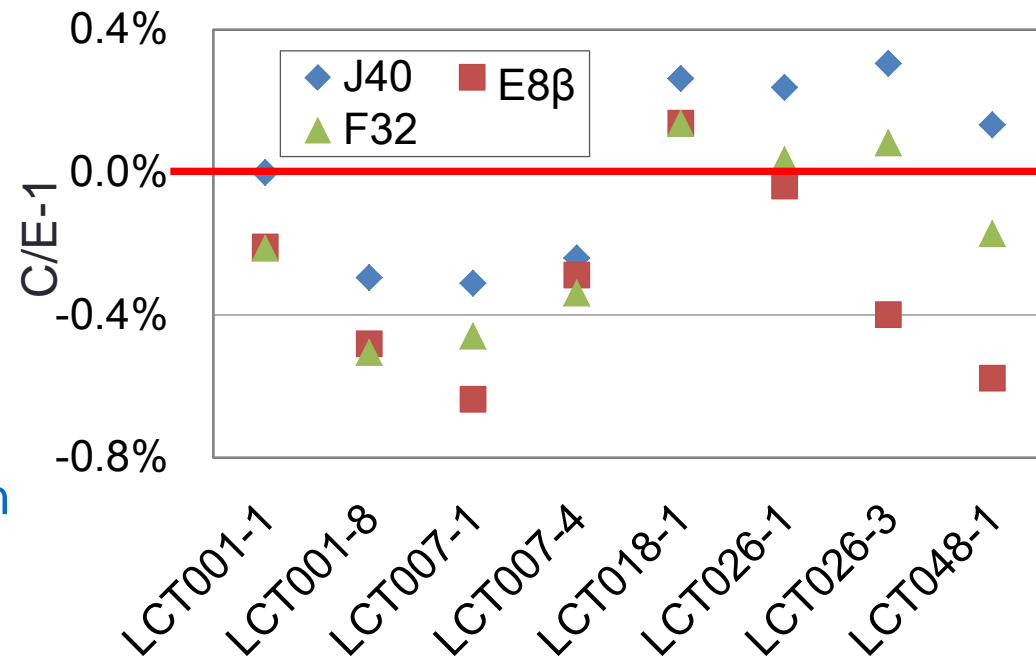
Characteristics of VACANCE (2/2)

- Drives two neutronics calculation codes
 - MVP and MCNP
- Extensibility is considered to easily add other calculation codes
 - FRENDY and MARBLE2 will be added in the near future
- Makes comparison table of C/E value
 - If experimental value is given, C/E value is automatically calculated
- Sort results by user-specified physical value
 - $^{235}\text{U}/\text{Pu}$ Enrichment, H/U ratio, temperature, and so on



Example

- Estimating the impact of the nuclear data difference
 - Comparison among calculation results using several nuclear data library is important to validate nuclear data
- VACANCE improves efficiency of this comparison
 - Many steps are required to compare the calculation results
 - Modification of input files, evaluation of k-eff, calculation of C/E value and edit results
 - VACANCE automatically runs above steps with simple input file



【 Comparison of C/E-1 value of keff changing nuclear data of ^{238}U 】

Summary of nuclear data validation

Validation process towards JENDL-5 is in progress

1. Development of nuclear data processing system, FRENDY, has been successfully started
2. Two recommended benchmark sets for LWR selected carefully from ICSBEP and IRPhEP have been determined
3. New automatic nuclear data validation system, VACANCE, will significantly reduce workloads and human errors in the validation process