Application of Nuclear Data to Fast Reactor Analysis and Design

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Objectives & Contents

- Objectives
  - To introduce the Current Status of Nuclear Data Application to Fast Reactor Cores in JAEA

- Contents

  (1) Group Constants and Analytical Tools Related to Nuclear Data

  (2) Consistent Evaluation of Nuclear Data and Improvement of Prediction Accuracy by the Database for Fast Reactor Experiments

  (3) Nuclear Data Processing System on Reactor Analysis Framework MARBLE

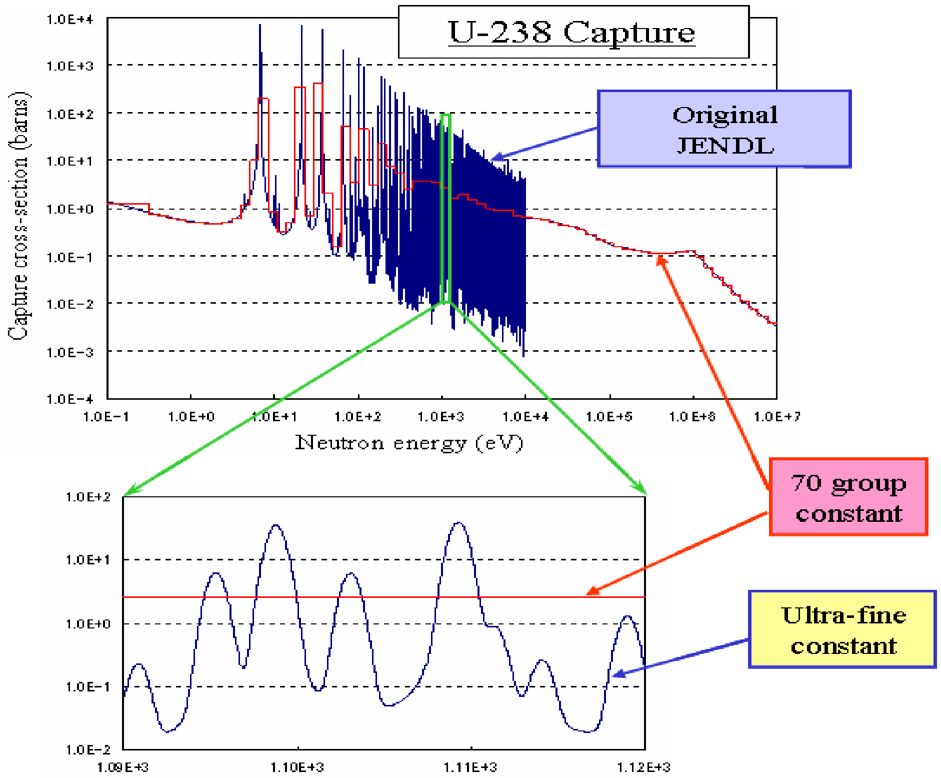
(1) Group Constants and Analytical Tools Related to Nuclear Data

Generation of New Group Constant Set (1/2)

- Background (as of 2001)
  - Standard: 70-group ABBN-type with self-shielding factor tables
  - Weighting function: Assumed a typical sodium-cooled MOX cores
  - Defect of ABBN: Inability to treat resonance-peak interaction effect among different nuclides
- Solution
  - Development of new group constant set (UFLIB) and new cell code (SLAROM-UF)
    - New ultra-fine energy group (~100,000 for < 50eV) constant structure
    - Selectable fine group (70, 73, 175, 900) constant sets

Generation of New Group Constant Set (2/2)

Ultra-fine Group Structure compared with Conventional 70-group Constant



Effect of the New Group Constant, SLAROM-UF Format

Nuclear Parameters Measured	Experimental Cores	C/E (Calculation/Experiment) **values** Old (ABBN, 70-group)	→ New (SLAROM-UF)
Criticality	**ZPPR-9**	0.9934	0.9955
	BFS-62-3A	0.9968	0.9985
Sodium Void Reactivity	**ZPPR-9**	1.03	0.98
	BFS-62-3A	**0.71**	**0.97**
Sample Doppler Reactivity	**ZPPR-9**	**0.91**	**0.96**
	BFS-62-4	**0.86**	**0.95**

→ Now, used as the standard tool for fast reactor analysis

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Development of Covariance Processing Code

- Background (as of 2001)
  - Needs to evaluate the prediction accuracy of reactor core parameters with clear accountability,
  - Existing utility codes did not fully satisfy our needs
    - Necessity to process the covariance data of:
      - The Reich-Moore resolved-resonance parameters,
      - Unresolved-resonance parameters,
      - P1 components of elastic scattering for scattering average cosine,
      - Secondary neutron energy distributions of fission reaction.
- Solution
  - Development of nuclear data covariance processing code ERRORJ

→ Now, integrated into ERRORR module of NJOY

(2) Consistent Evaluation of Nuclear Data and Improvement of Prediction Accuracy by the Database for Fast Reactor Experiments

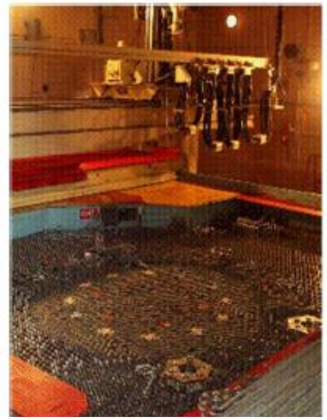
Database of Fast Reactor Experiments and Unified Cross-section Set

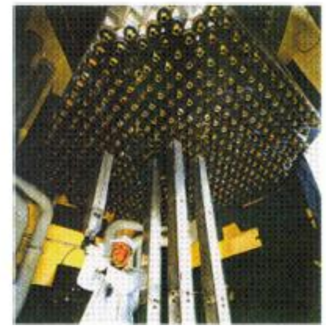
- Objectives
  - Importance of the integral experimental data to verify the quality of evaluated nuclear data libraries
    - For the last two decades, JAEA has made efforts to collect the fast reactor experimental data from their original documents, and continued to evaluate those data, by applying JENDL and the most detailed analytical methods.
  - To improve the design accuracy of power reactor cores for assuring safety, reliability and economy
    - All related information including C/E values, experimental and analytical uncertainties, sensitivity coefficients of various experimental cores and parameters, and cross-section covariance, should be synthesized.

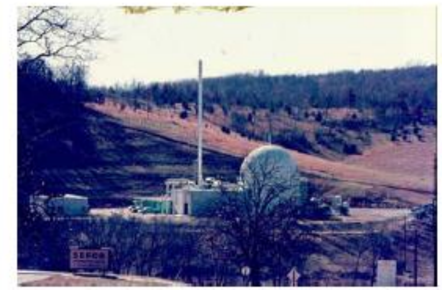
Development of Standard Database for Fast Reactor Experiments

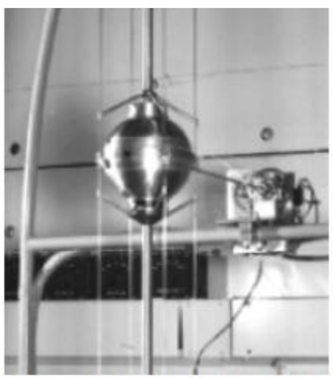

(US) ZPPR (321)


(UK) ZEBRA (27)

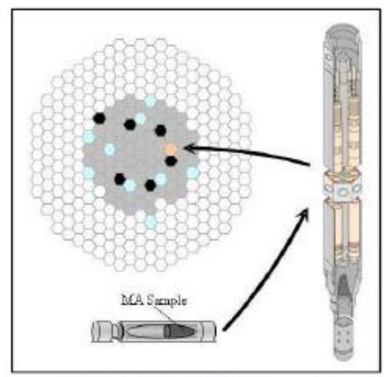

(Russia) BFS (187)


(France) MASURCA (14)


(US) SEFOR (10)


(US) LANL small core (5)


(Japan) JOYO MK-I (26)



(Japan) JOYO MK-II (43)


(Japan) MONJU (10)

- Total number of nuclear characteristics is 643
- Many of these data were used for JENDL-4.0 benchmark
- Some of these data have been registered to IRPhEP handbook

Unified Cross-section Set based on Bayesian Adjustment Technique

Theory of Cross-section Adjustment

- Based on the Bayes theorem, i.e., the conditional probability estimation method
  → To maximize the posterior probability that a cross-section set, ***T***, is true, under the condition that the information of integral experiment, ***Re***, is obtained.

$$J(T) = (T-T_0)^t M^{-1}(T-T_0) + [Re-Rc(T)]^t[Ve+Vm]^{-1}[Re-Rc(T)]$$

Minimize the function $J(T)$. → $dJ(T)/dT = 0$

- The adjusted cross-section set T', and its error (covariance), M'

$$T' = T_0 + MG^t[GMG^t+Ve+Vm]^{-1}[Re-Rc(T_0)]$$

$$M' = M - MG^t[GMG^t+Ve+Vm]^{-1}GM$$

- Prediction error induced by the cross-section errors

Before adjustment : GMG^t After adjustment : $GM'G^t$

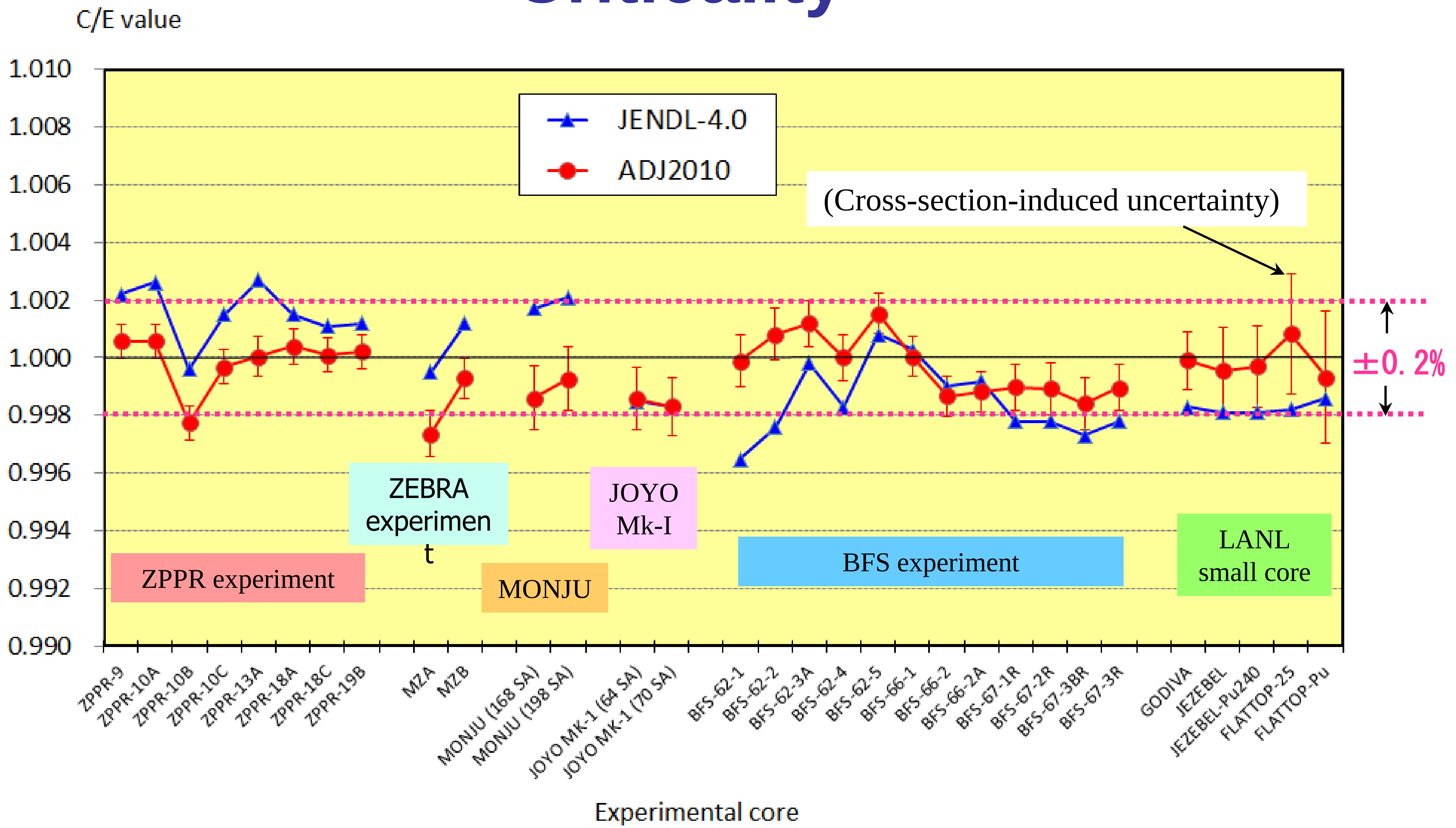
Where, T_0 : Cross-section set before adjustment
M : Covariance before adjustment
Re : Measured values of integral experiments
Rc : Analytical values of integral experiments
Ve : Experimental errors of integral experiments
Vm : Analytical modeling errors of integral experiments
G : Sensitivity coefficients, $(dR/R)/(d\sigma/\sigma)$

History of Unified Cross-section Set

Item	ADJ91	ADJ2000	ADJ2010
Basic library (Release year)	JENDL-2 (Final 1989, First 1982)	JENDL-3.2 (1994)	JENDL-4.0 (2010)
Nuclear parameters to be adjusted	σ_∞ of 11 nuclides (32 reactions), χ of 2 nuclides, β of 6 nuclides	σ_∞ of 11 nuclides (41 reactions), χ of 2 nuclides, β of 6 nuclides, Self-shielding factors of U-238	σ_∞ of 27 nuclides (155 reactions), χ of 2 nuclides, β of 11 nuclides, Pseud-FP of 4 fissiles, Self-shielding factors of U-238
Energy structure	18 group	18 group	70 group (lethargy width of each group: 0.25)
Covariance of nuclear data	Rough estimation from differences between measured values and JENDL-2	The covariance data file evaluated after JENDL-3.2 release	The covariance data evaluated and released simultaneously with JENDL-4.0
Integral experimental data	82 data from JUPITER experiment at ZPPR	237 data from JUPITER, FCA, JOYO, BFS, MASURCA and Los Alamos (including burnup and temperature data)	488 data from JUPITER, ZEBRA, JOYO, MONJU, BFS, MASURCA, SEFOR and Los Alamos (including burnup, temperature and MA post-irradiation test data)

Performance of ADJ2010 Library (1/2)

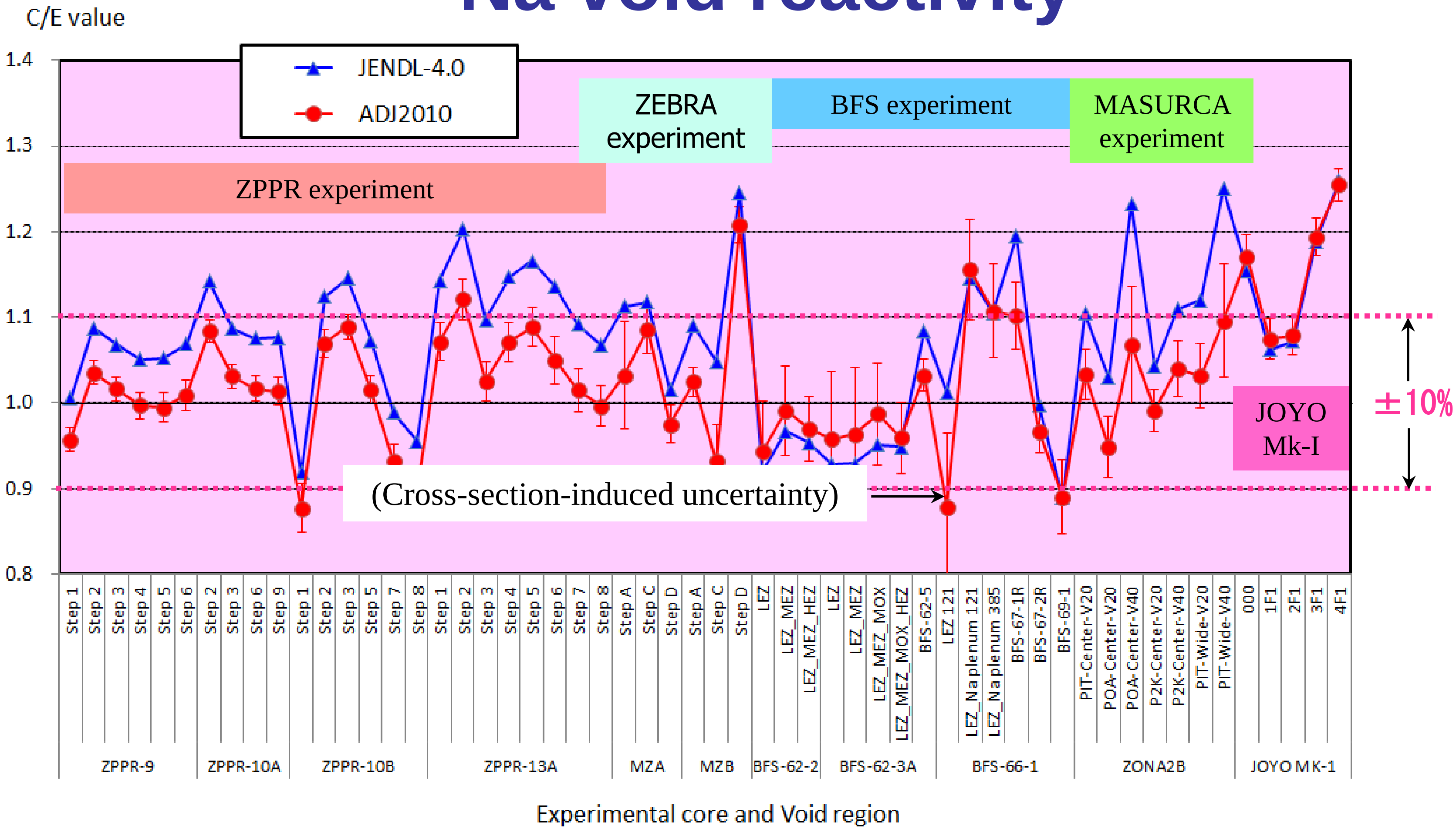
- Criticality -



- The adjusted C/E values of criticality after adjusted are within ±0.2% Δk.
- The good performance is not only for Pu-fuel cores, but enriched-U fuel cores.

Performance of ADJ2010 Library (2/2)

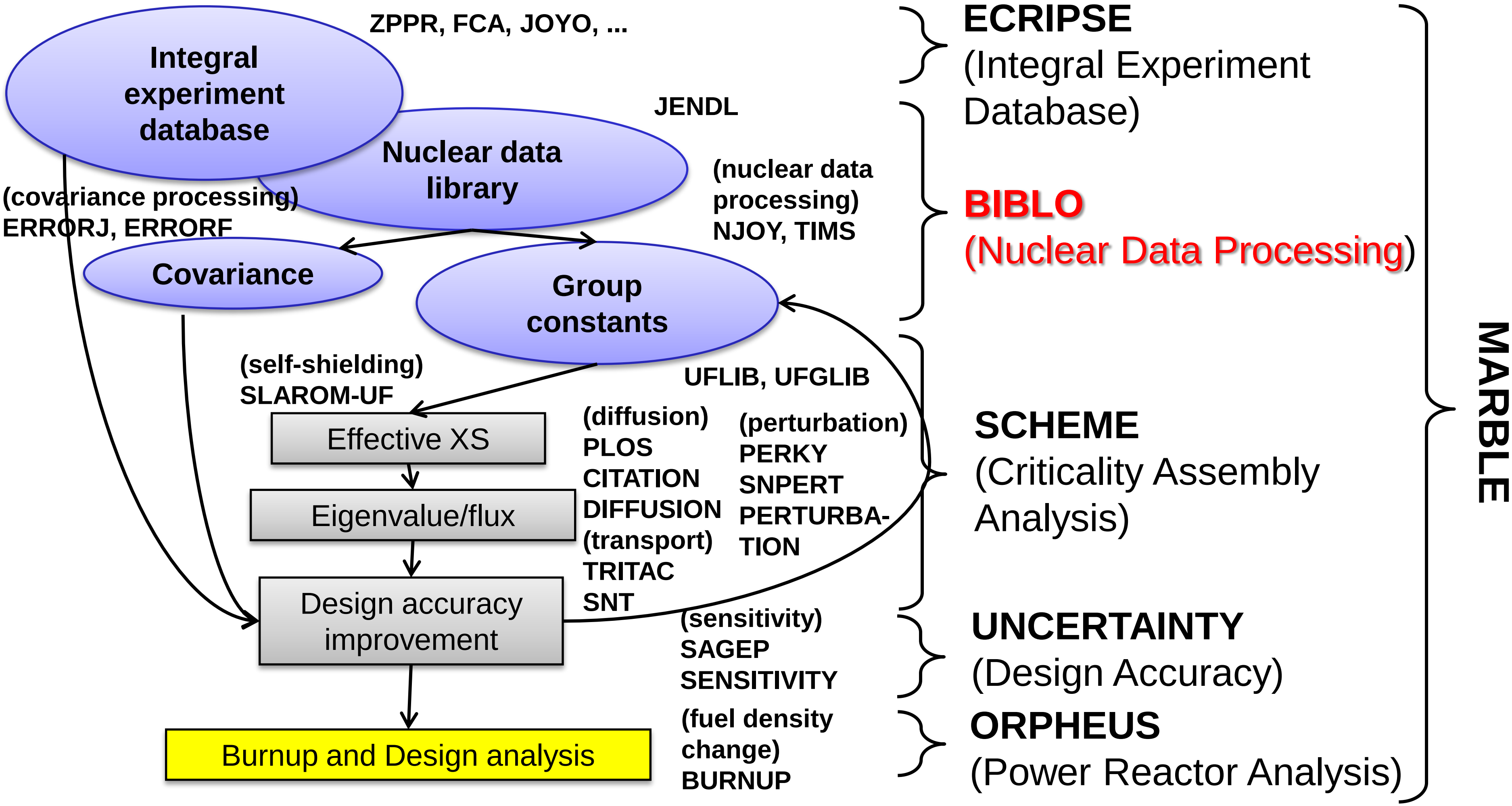
- Na void reactivity -



■ The adjusted C/E values of Na void reactivity are mostly within ±10%.

(3) Nuclear Data Processing System on Reactor Analysis Framework MARBLE

MARBLE Framework



- ❑ Unification of tools both for neutronics analysis and nuclear data processing
- ❑ Coverage of all phases required in fast reactor core design

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BIBLO system (1/4)

- Background (as of 2008)
  - Problems in the existing SLAROM-UF library (UFLIB) creation system based on FORTRAN and Unix shell script
    - Restriction in setting energy group, library name and so on
    - Poor readability of pre- and post-processing FORTRAN codes
    - Poor extendibility
    - Complicated system
- Solution
  - Reconstruction of UFLIB creation system on MARBLE
    - Efficient development by
      - Reuse of modules and framework already developed in MARBLE
      - Test-driven development (also known as Test First)
      - Version control system (Subversion)
      - Issue tracking system (Trac)
  - The new system is named as BIBLO

BIBLO system (2/4)

- ENDF, PENDF, GENDF and CVF (output of NJOY ERRORR) files are treated as Python objects.
  - Data (basic data, cross section data, covariance data) are easily picked up with implemented methods.

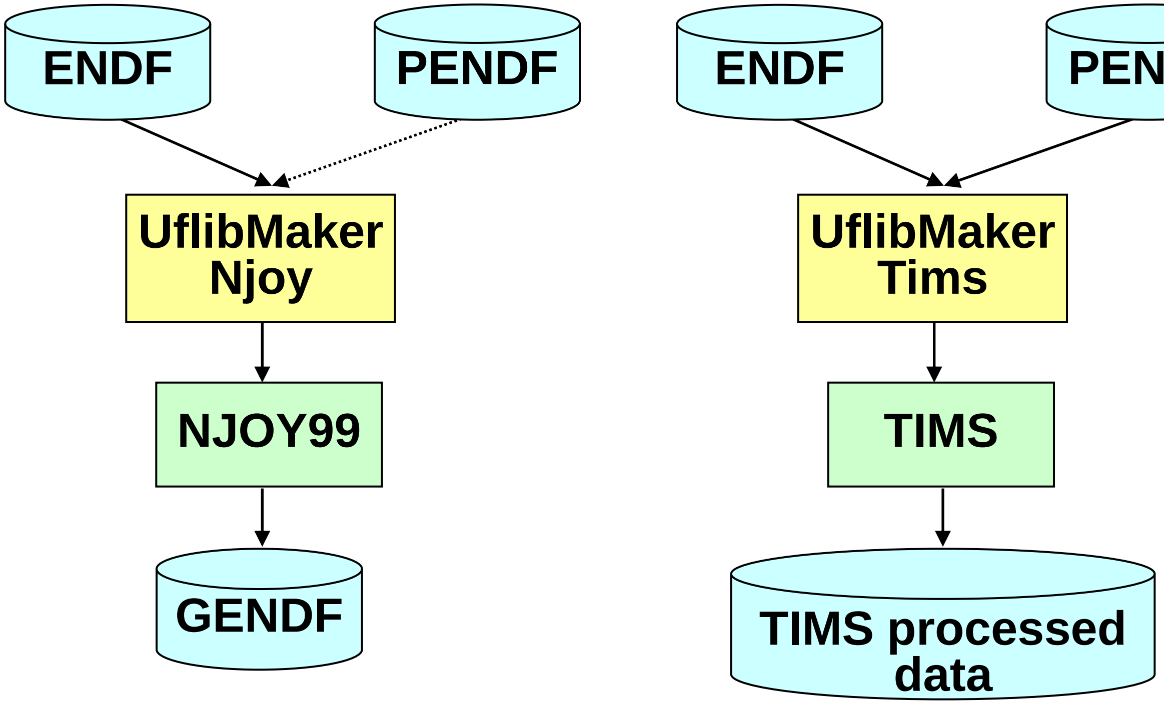
(Example)

```
endf  = ENDF(path=xxxxx)
mat = endf.mat()
qvalue = endf.rdQval(mt=18)
potential_scattering = endf.pots()
upper_esonance_energy = endf.ureh()
xs = endf.rdMF3xs(mt=18)
```

```
gendf  = GENDF(path=xxxxx)
energy_boundary = gendf.eb()
xs = gendf.rdMF3xs(mt=2)
matrix = gendf.rdMF6xs(mt=2)
```

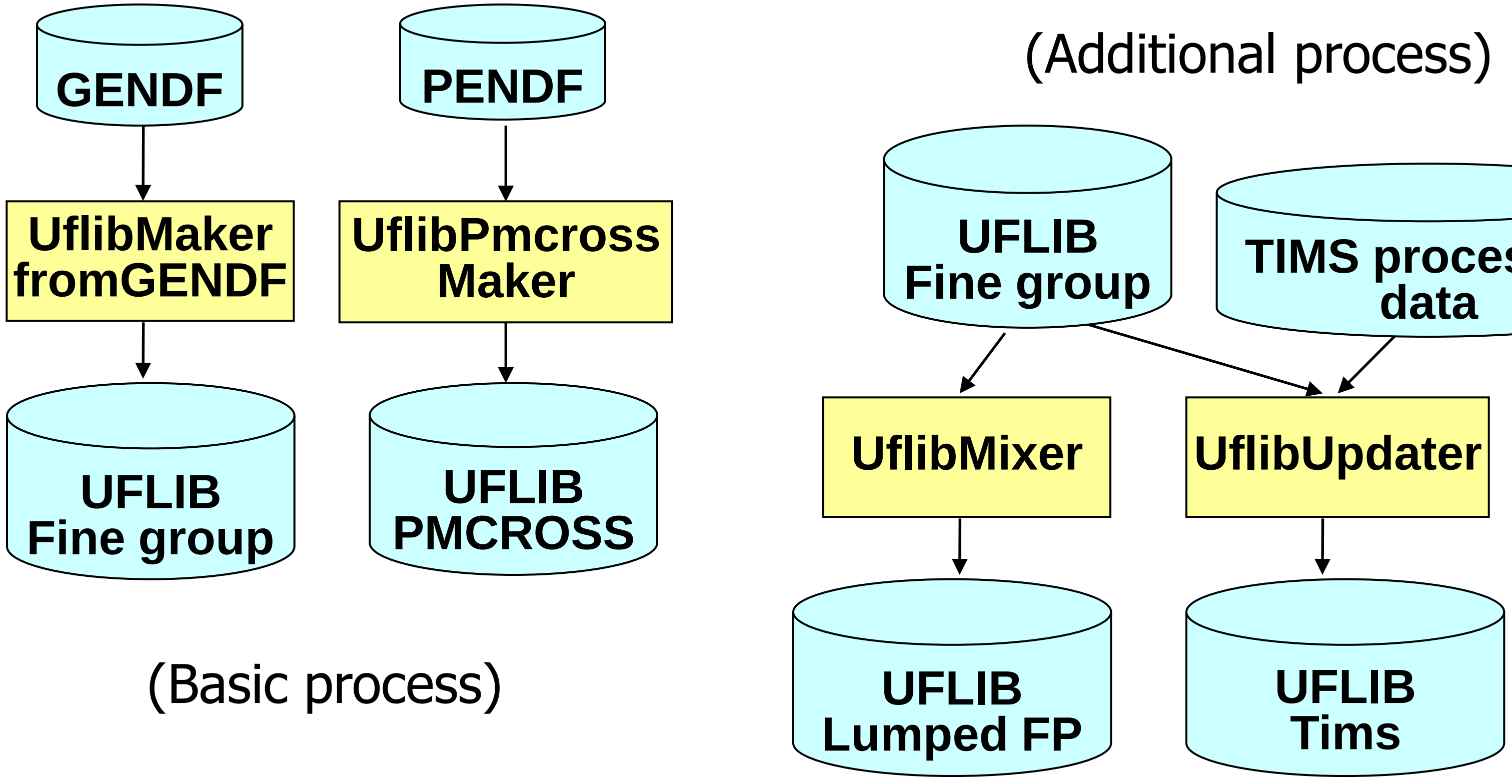
BIBLO system (3/4)

- NJOY and TIMS are encapsulated by Python modules.
  - Basic modules for encapsulation in MARBLE are reused.
  - Input data are automatically created.
  - Various modules in NJOY or TIMS are combined flexibly.



BIBLO system (4/4)

- GENDF, PENDF, and TIMS processed data are converted to UFLIB with Python modules.
  - All post-processing FORTRAN codes were replaced with newly developed Python modules.



Summary

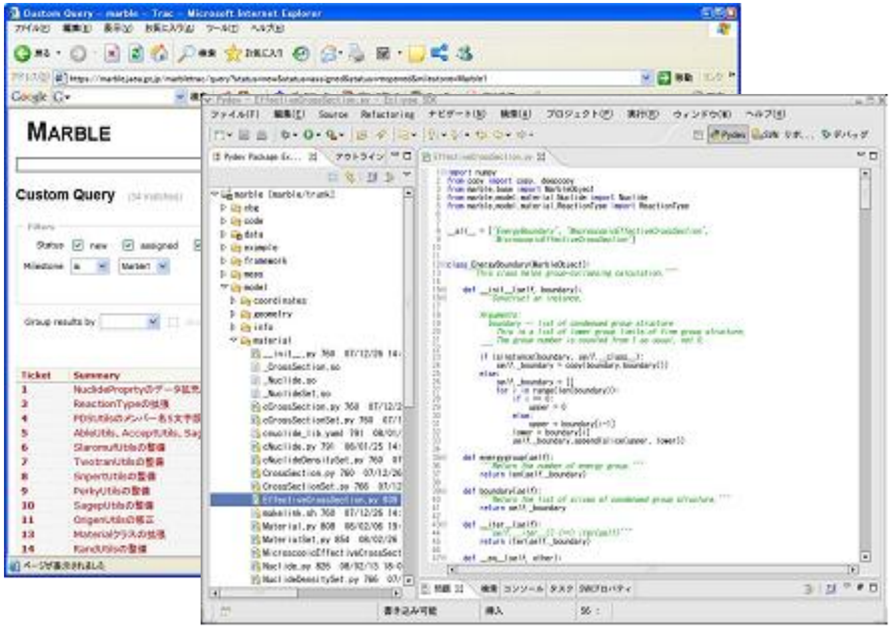
- The current status of nuclear data application to fast reactor analysis and design in JAEA
  - Development and utilization of the standard database for fast reactor experiments
    - Consistent evaluation and benchmark of JENDL-4.0
    - Unified cross-section set ADJ2010 based on Bayesian adjustment technique
  - Group constant set and nuclear data related tools
    - Ultra-fine group constant set UFLIB
    - Covariance processing code ERRORJ
    - New nuclear data processing code system BIBLO on MARBLE

Appendix

- Software Development Methodology and Tools in MARBLE

MARBLE Development Methodology

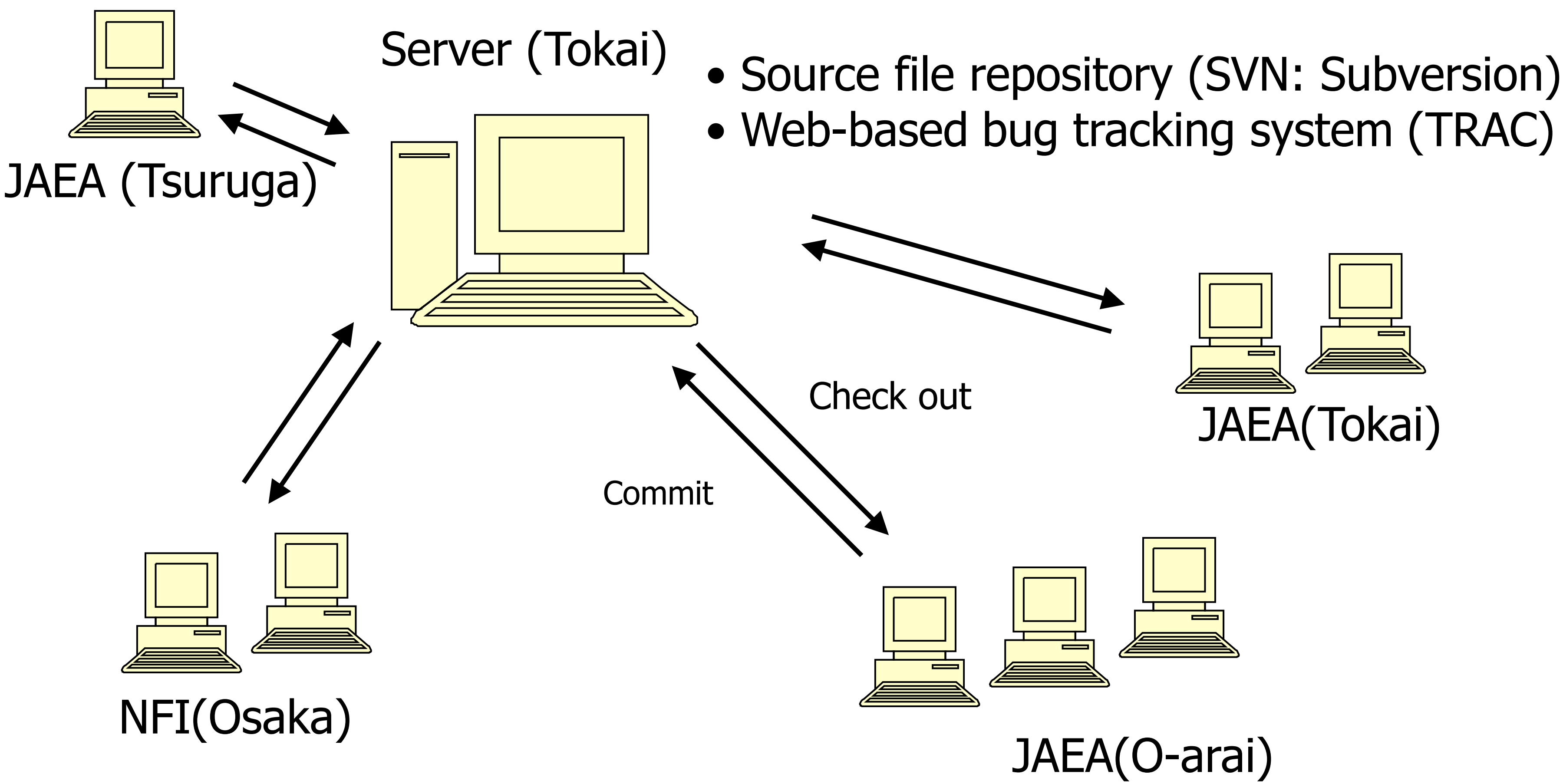
- Object-Oriented Analysis and Design
  - Modeling in UML（Unified Modeling Language）
  - Agile Development Scheme
  - Iterative and incremental development
  - Test-first programming
  - Active refactoring, …etc.



- Rapid Implementation with Python Scripting Language
- Development Tools
  - Subversion(version control), Trac (bug tracking), Eclipse (IDE) etc.

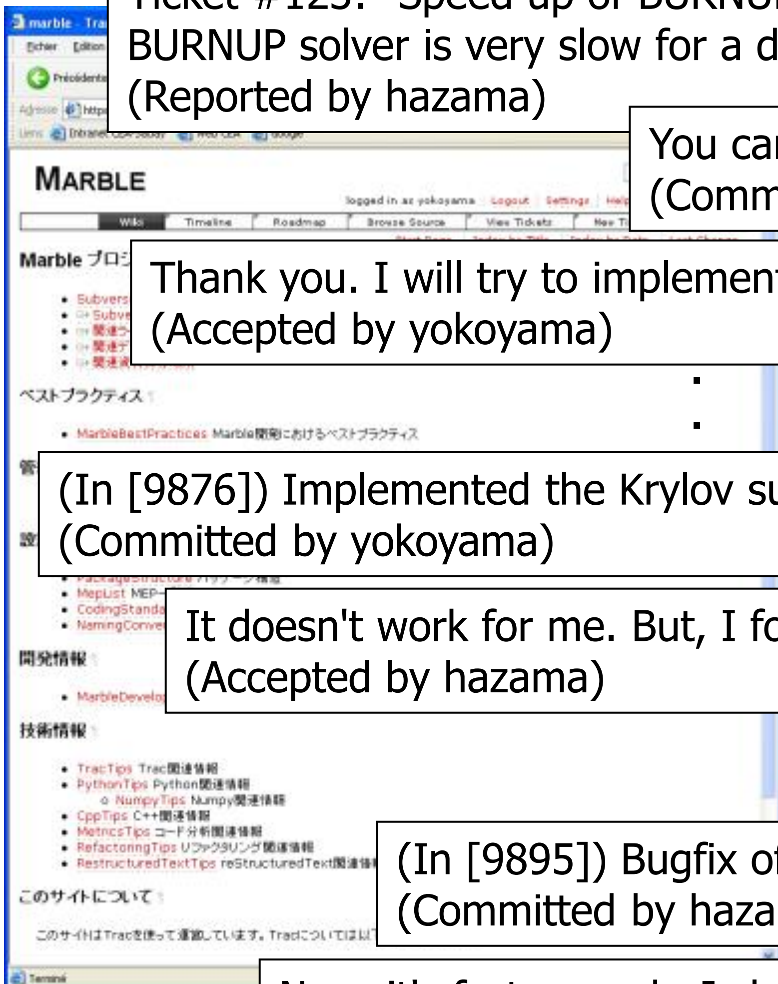
Improved quality and efficiency in development using modern practices and tools

MARBLE Development on the Internet



- Each developer works with source files copied from the repository
- Any developer can change the source files on the repository

Example: Development with TRAC and SVN



Ticket #123: "Speed up of BURNUP solver" BURNUP solver is very slow for a detailed chain. Tune it! (Reported by hazama)	**Ticket created (TRAC)**
You can use the Krylov subspace method. (Commented by tatsumi)	**Comment (TRAC)**
Thank you. I will try to implement it. (Accepted by yokoyama)	**Ticket accepted (Trac)**
:	**modifying the source files**
(In [9876]) Implemented the Krylov subspace method (refs #123) (Committed by yokoyama)	**Source changed (SVN)**
It doesn't work for me. But, I found a bug, that is, ... (Accepted by hazama)	**Ticket re-accepted (TRAC)**
:	**modifying the source files**
(In [9895]) Bugfix of BURNUP solver (refs #123) (Committed by hazama)	**Source changed (SVN)**
Now, it's fast enough. I close this ticket. (Closed by hazama)	**Ticket closed (TRAC)**