Nuclear data needs for transmutation system

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16th ASRC International Workshop " Nuclear Fission and Structure of Exotic Nuclei "
JAEA Tokai, Japan 18-20.March.2014

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Benefit and role of P&T

- Benefits of P&T on Management of High-Level Radioactive Wastes (HLW):
  - ✓ Reduction of long-term radiological toxicity
  - ✓ Reduction of dose for future inhabitants

    } *To mitigate difficulties caused by long-term nature of radioactivity*

  - ✓ Reduction of amount of HLW
  - ✓ Reduction of repository size

    } *To extend capacity of a repository*

  - ✓ Recovery of valuable materials from wastes, and so on.

> ➢ Steady implementation of **High Level Waste (HLW) disposal** is one of the most important issues even though we select to reduce dependency on nuclear energy.
>
> ➢ **Partitioning and Transmutation (P&T)** will be a key technology to reduce the environmental burden of HLW.

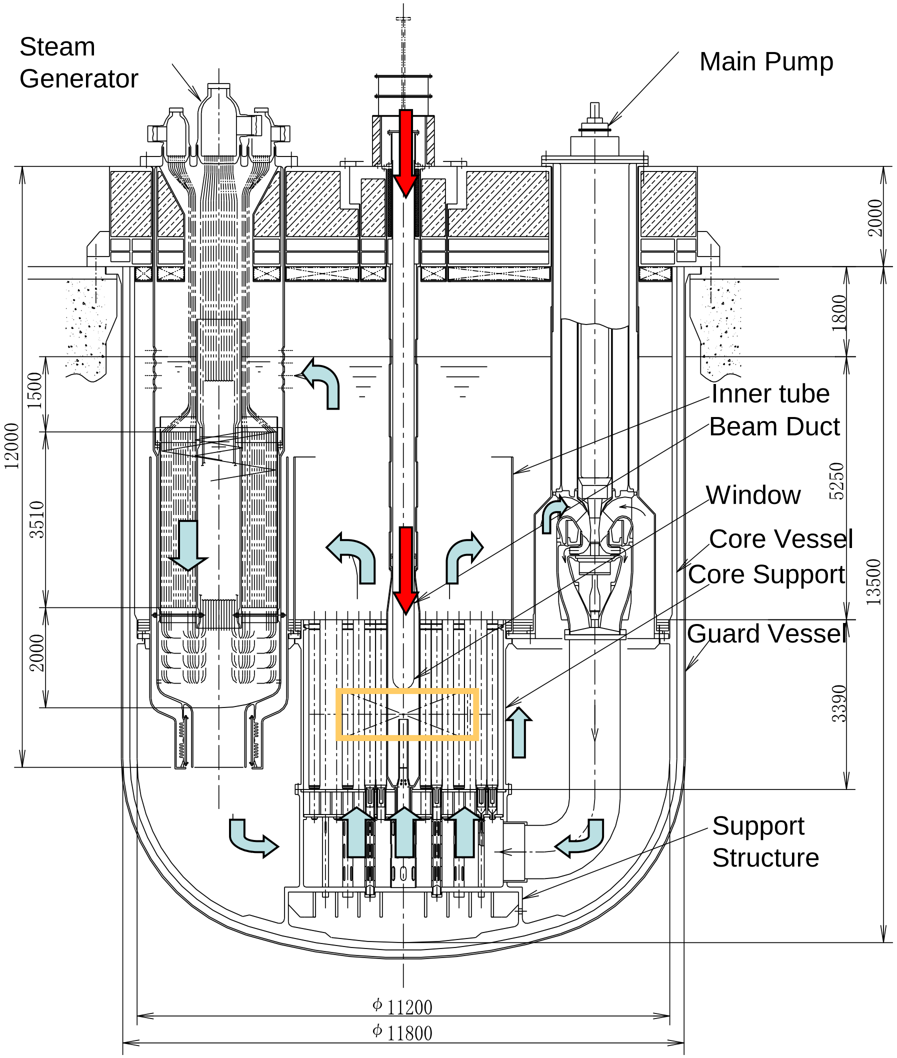
Conceptual Design of ADS in JAEA

Purpose : MA transmutation

- Proton beam : 1.5GeV ~20MW
- Spallation target : LBE
- Coolant : LBE
- Subcriticality : $k_{eff} = 0.97$
- Thermal output : 800MWt
- Core height : 1000mm
- Core diameter : 2440 mm
- Fuel inventory : 4.2t (MA:2.5t)
- Fuel composition :

  (MA + Pu)N+ZrN (Mono-nitride)
  Inner : 70%MA+30%Pu
  Outer : 54%MA+42%Pu
- Transmutation rate :

  250kg(MA) / 300EFPD



K. Tsujimoto, H.Oigawa, K.Kikuchi, et. al, "Feasibility of Lead-Bismuth-Cooled accelerator-Driven System for Minor-Actinide Transmutation", *Nucl. Tech.* 161, 315-328 (2008).

Allowable maximum k-eff for ADS

- High k-eff value implies low proton beam current and small power peaking, but risk of approaching criticality under accidental conditions will increase.
- **The subcriticality must be set to adequate level considering accidental insertion of reactivity and uncertainties for calculation and measured reactivity.**

Accidental insertion reactivity	%Δk/k
Beam tube filled with Pb-Bi[1)]	0.32
Unusual temperature rise of coolant Pb-Bi[2)]	0.69
Uncertainty for measurement[3)]	0.50
Uncertainty for calculation	1.00
Total	2.51

1) Pb-Bi entry to the vacuum beam tube by failure of the beam window

2) Coolant temperature rise of 1000K in only fuel region by coast down

3) Accuracy of β_{eff} influences directly

K. Tsujimoto, T.Sasa, K.Nishihara, et. al, "Neutronics Design for Lead-Mismuth Cooled Accelerator-Driven System for Transmutation of Minor Actinide", *J. Nucl. Sci. Tech.*, 41, 21-26 (2004).

→ Allowable maximum k-eff was set at **0.97**

Benchmark calculation

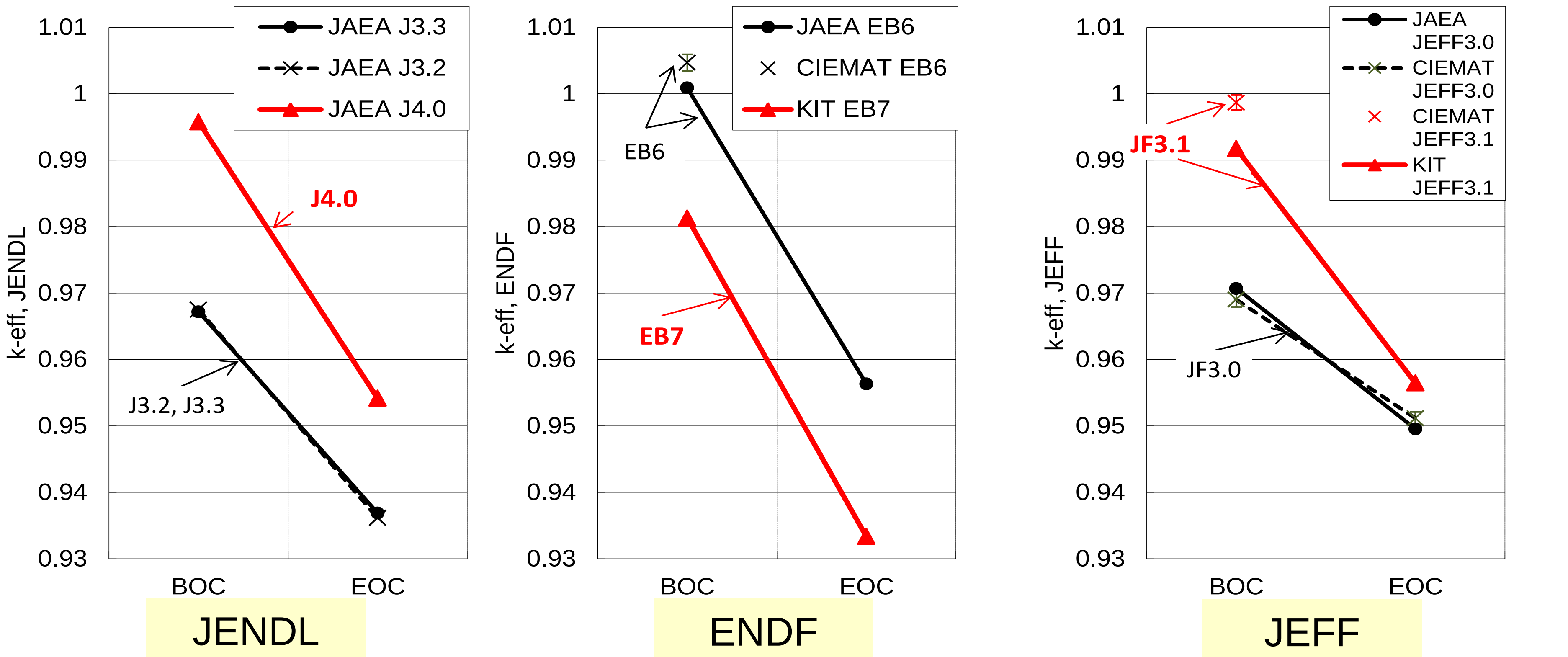
- **To survey current status of neutronics design accuracy for ADS**, benchmark calculations were performed in framework of IAEA-CRP. Benchmark problem was based on the ADS design proposed by JAEA.

Participant	Code	Library
JAEA (Japan)	**PHITS, NMTC** or **MCNPX** (MC code for proton and neutron >20MeV) **SLAROM** (Cross section code) **TWODANT** (Deterministic neutron transport code) **ORIGEN** (Burn-up code)	JENDL-3.3 JENDL-4.0 JENDL-3.2 ENDF/B-VI JEFF-3.0
CIEMAT (Spain)	**EVOLCODE2** (MCNPX-based burnup code)	JEFF-3.0 (JEFF-3.1) [a)] (ENDF/B-VI) [a)]
KIT (Germany)	High energy particles are not analyzed. **C4P**, **ZMIX** (Cross section code) **DANTSYS** (Deterministic neutron tansport code) **TRAIN** (Burn-up code)	ENDF/B-VII JEFF-3.1

[a)] Library in parenthesis is only for the beginning of cycle (BOC).

Current status of neutronics design of ADS (1/2)

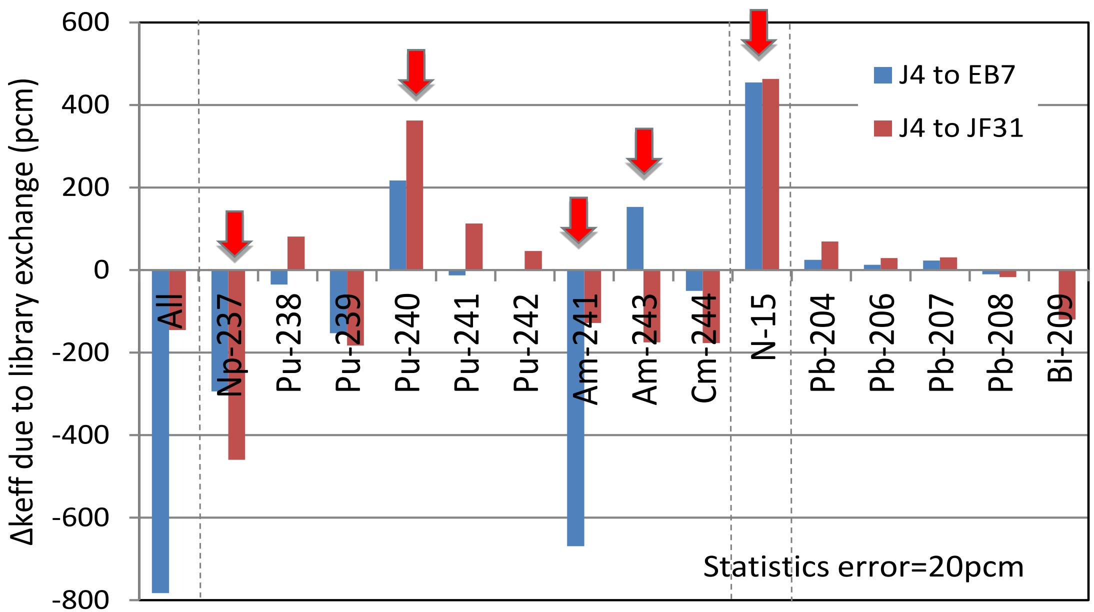
- **About 2% discrepancies in k-eff were found among the different nuclear data libraries** in a IAEA-CRP benchmark proposed to survey current status of calculation accuracy of ADS by JAEA.

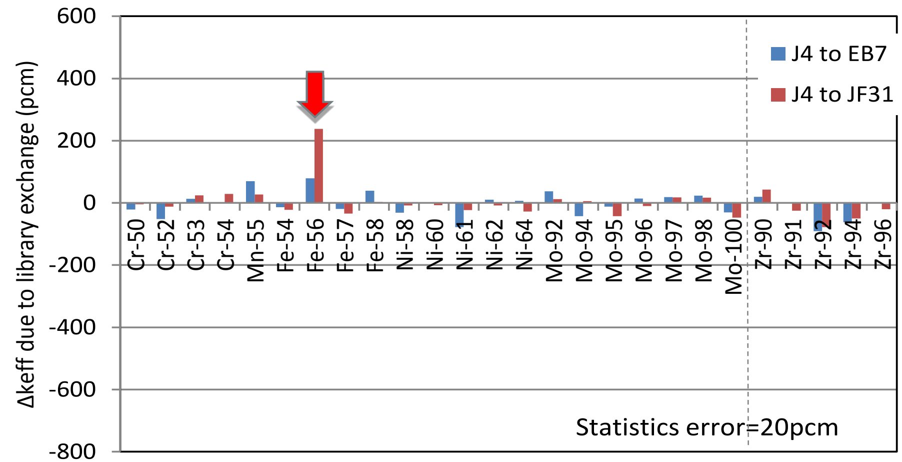


A. Stanculescu, "The IAEA Coordinated Research Project (CRP) on "Analytical and experimental benchmark analyses of accelerator driven systems," OECD/NEA 11th Information Exchange Meeting, San Francisco, 1-4 Nov. 2010. (2010)

Calculated results for IAEC-CRP benchmark proposed by JAEA (Burnup calculation for the first burnup cycle of 600 EFPD with 800MWth ADS)

Current status of neutronics design of ADS (2/2)





Δkeff due to library exchange of single nuclide from JENDL-4 to ENDF/B-VII or JEFF-3.1 estimated by MCNPX.

- Identification of typical contributors for the differences among the calculated k-eff values with different nuclear data library, JENDL-4.0 ENDF/B-VII, and JEFF-3.1

Np-237, Pu-240, Am-241, Am-243, N-15, Fe-56

Cause of difference for calculation results

- The cause of the difference between the calculation results with JENDL-4.0 and JENDL-3.3 are the cross section of

Am-241, Pb-206, and Pb-207.

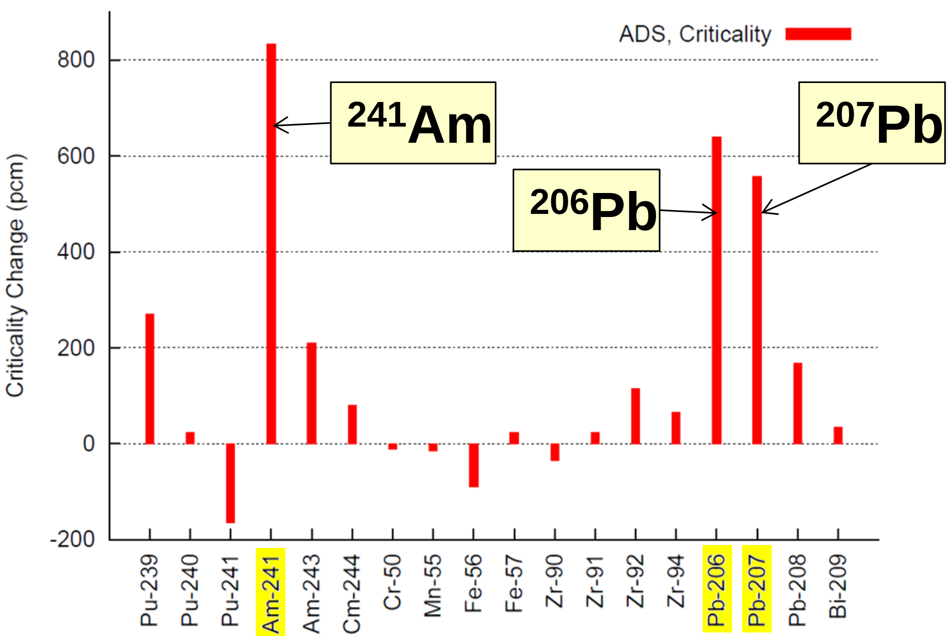


Fig. Nuclide-wise contribution for the difference between calculated k-eff with JENDL-4.0 and 3.3

Table Reaction-wise contributions for the difference between calculated k-eff with JENDL-4.0 and 3.3

	fis	ν	cap	inl	el	μ
^{241}Am	76	**208**	**255**	**293**	1	1
^{206}Pb	—	—	-34	**674**	3	-5
^{207}Pb	—	—	-14	**560**	14	-4

H. Iwamoto, K. Nishihara, T. Sugawara and K. Tsujimoto, "Sensitivity and Uncertainty Analysis for a Minor-Actinide Transmuter with JENDL-4.0", Proc. ND2013, March 4 – 8, 2013, New York, U.S.A. (2013).

Summary of IAEA-CRP benchmark

- Small difference between participants (codes) with same library.
- k-effective disperse from 0.98 to 1.0 at BOC and 0.93 to 0.96 at EOC.

To design an ADS is very difficult, if estimated k-effective changes 2 to 3 %dk.

⇒ **Uncertainty should be evaluated.**

Uncertainty evaluation results for k-eff

Total uncertainty: 1.04%Δk Covariance data in JENDL-4.0

- **The uncertainty for k-eff of 1% is smaller than the result of IAEA benchmark activity (2-3%).**

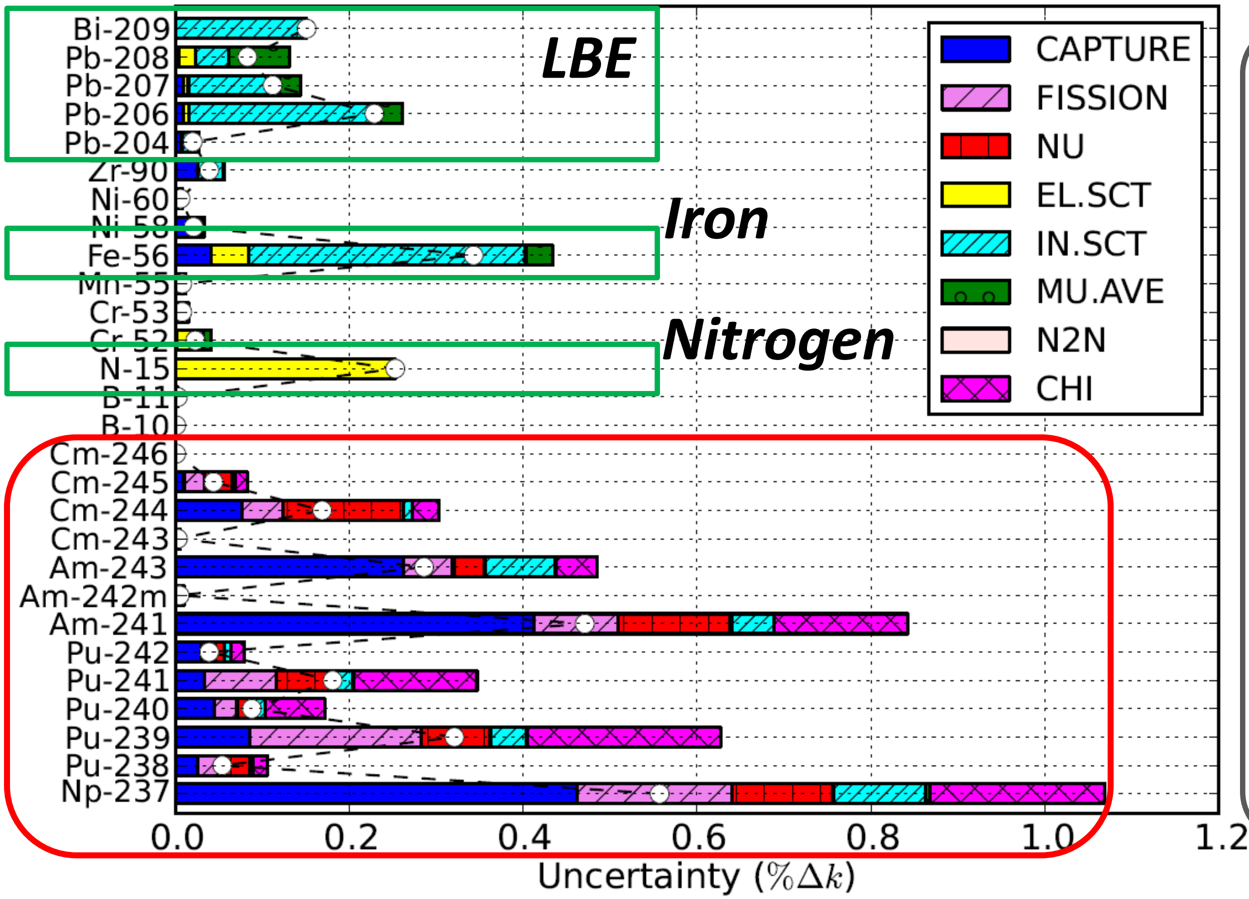


Fig. Nuclear- and reaction-wise Breakdown of criticality uncertainty

Major contributions to uncertainty

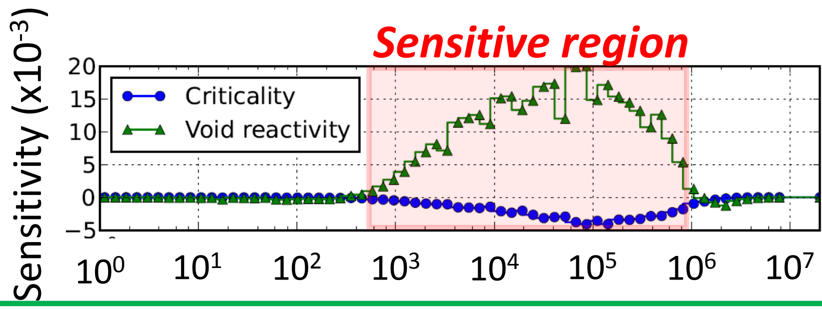
Pb, Fe-56
- **Inelastic scattering**

N-15
- **Elastic scatterring**

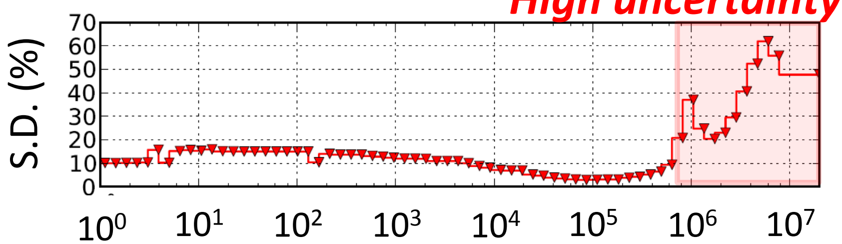
MA, Pu
- **Capture cross section**
- **Fission spectrum**
- **Fission cross section**

^{241}Am capture cross section

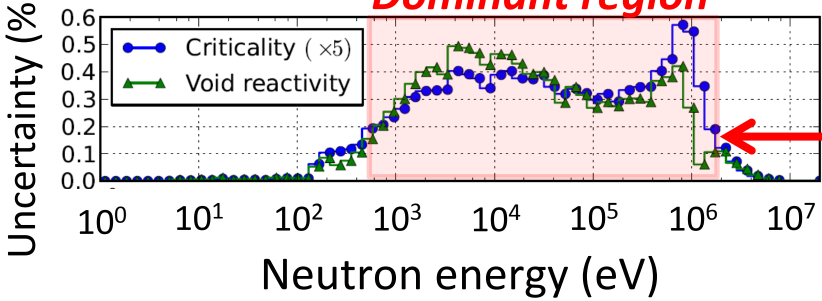
- **Sensitivity coefficients**



- **Covariance data (1σ S.D.)**



- **Energy breakdown of uncertainties**



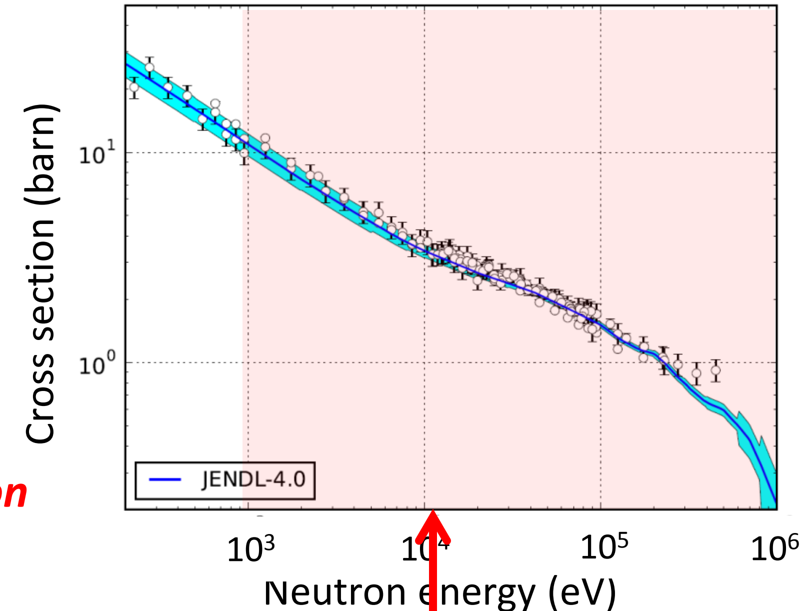
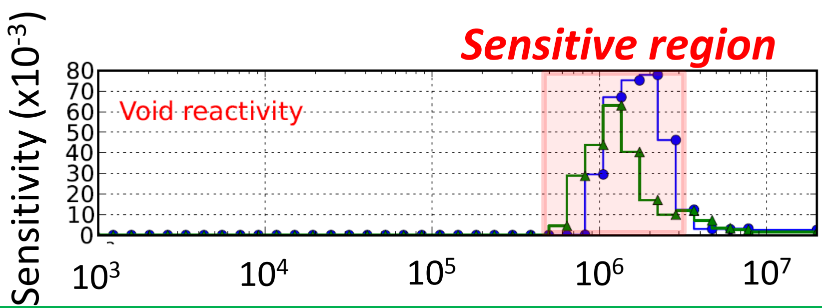


Fig. ^{241}Am capture cross section

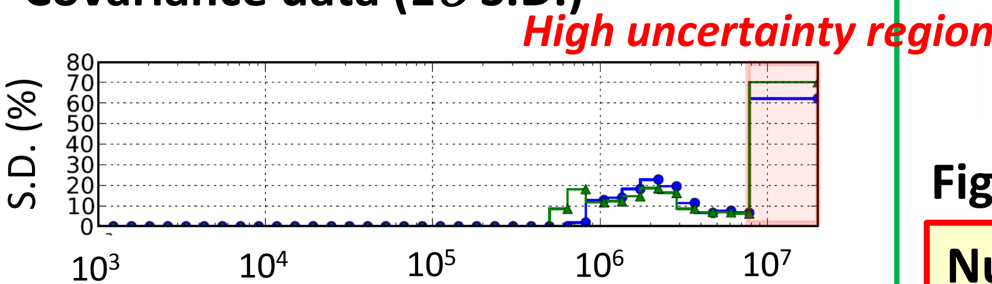
Nuclear-data evaluation in this region (From ~1 keV to 1 MeV) affects the uncertainties in the integral parameters!

^{206}Pb inelastic cross section

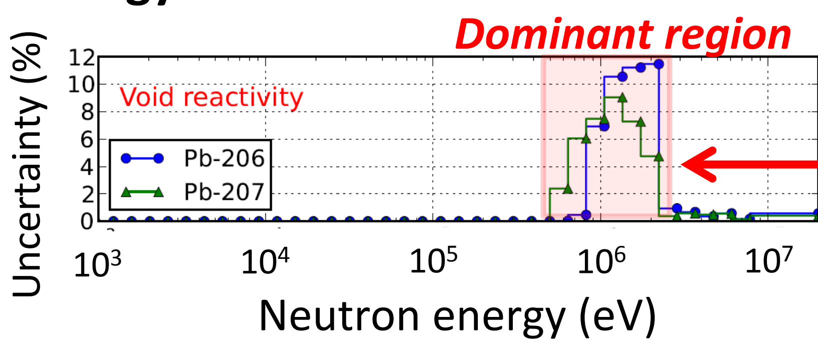
- **Sensitivity coefficients**



- **Covariance data (1σ S.D.)**



- **Energy breakdown of uncertainties**



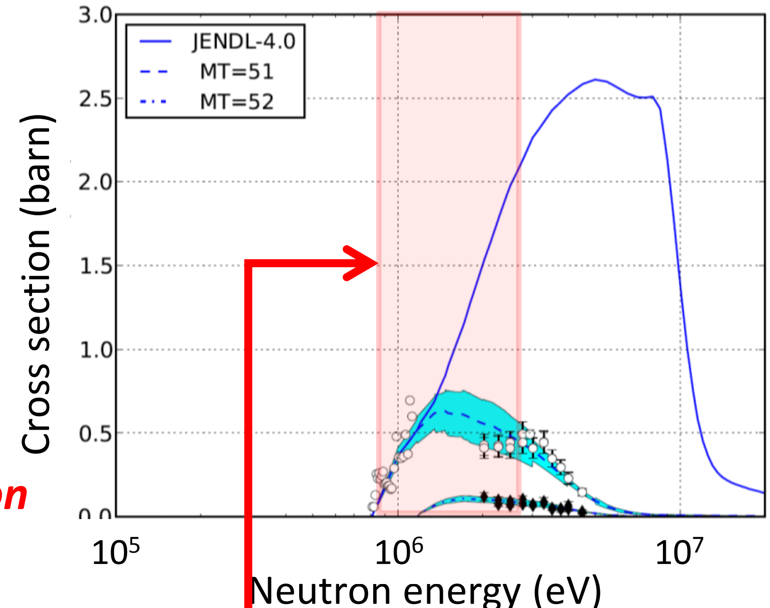


Fig. ^{206}Pb inelastic scattering cross section

Nuclear-data evaluation in this region (From threshold to ~3MeV) affects the uncertainties in the integral parameters of the ADS.

Summary

- **The current status of nuclear data is not so satisfactory for the neutronics design of ADS as MA transmutation system.**
  - The benchmark results for the neutronics parameters of ADS showed that there were large differences among the calculated parameters with different nuclear data libraries. For example, the differences for the calculated k-eff values were approximately 3%.

- **Improvement of nuclear data, not only for MA and Pu but also other nuclide (Pb, N-15), is significantly necessary for transmutation system.**

- **In order to meet the requirements for the nuclear data to improve the design accuracy, continuous effort including not only differential experiments but also the integral experiments are important issue.**