Sensitivity and Uncertainty Analysis for a Minor-Actinide Transmuter with JENDL-4.0

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Accelerator-Driven System (ADS)

To transmute minor actinides (MAs) , JAEA has conducted R&D activities on an **ADS** loaded with large amount to MA.

Table Characteristics of the ADS

Thermal power	800 MW_{th}
Type	Lead-bismuth eutectic (LBE) cooled tank type
Proton beam	1.5 GeV (10-20 mA)
Target	LBE with a beam window
Max. criticality	k_{eff} = 0.97
Fuel in core	nitride fuel, (MA+Pu)N+ZrN MAN:PuN:ZrN~ 33:17:50 (wt%)
Amount of MA	2.5 tons
Transmutation ratio	10% MA/year

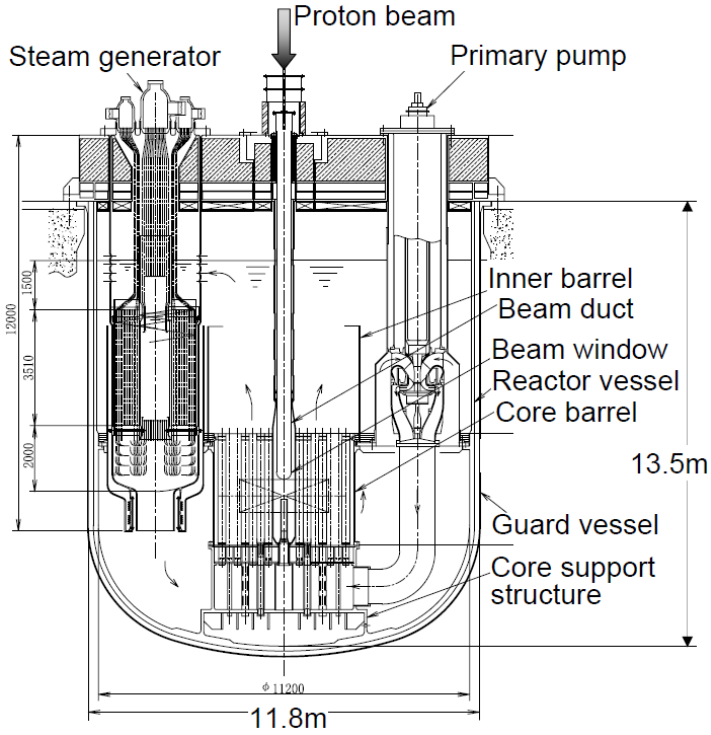


Fig. Design of the ADS plant

Covariance data in JENDL-4.0

Table Status of JENDL-4.0 covariance data related to the ADS

	σ_{fis}	ν	χ	σ_{cap}	σ_{el}	σ_{inl}	σ_{n2n}	μ
Pu-238	R	R	R	R	R	R	R	R
Pu-239	R	R	R	R	R	R	R	R
Pu-240	R	R	R	R	R	R	R	R
Pu-241	R	R	R	R	R	R	R	R
Pu-242	R	R	R	R	R	R	R	R
Np-237	R	R	R	R	R	R	R	R
Am-241	R	R	R	R	R	R	R	R
Am-242m	R	R	R	R	R	R	R	R
Am-243	R	R	R	R	R	R	R	R
Cm-243	R	R	R	R	R	R	R	R
Cm-244	R	R	R	R	R	R	R	R
Cm-245	R	R	R	R	R	R	R	R
Cm-246	R	R	R	R	R	R	R	R

R: Data have been already evaluated.

E: **Newly evaluated!**

	σ_{cap}	σ_{el}	σ_{inl}	σ_{n2n}	μ
B-10	R	R	N/A	N/A	N/A
B-11	R	R	N/A	N/A	N/A
N-15	N/A	R	N/A	N/A	N/A
Cr-52	R	R	R	R	R
Cr-53	R	R	R	R	R
Fe-56	R	R	R	R	R
Mn-55	R	R	R	N/A	R
Ni-58	R	R	R	R	R
Ni-60	R	R	R	R	R
Zr-90	R	N/A	R	R	N/A
Pb-204	E	E	E	E	E
Pb-206	E	E	E	E	E
Pb-207	E	E	E	E	E
Pb-208	E	E	E	E	E
Bi-209	N/A	N/A	R	N/A	N/A

- Many covariance data were evaluated in JENDL-4.0.
- Covariance data of **Pb isotopes** has been added.

Analysis

1. To derive integral parameters of the ADS with JENDL-4.0, and to investigate the cause of the differences from JENDL-3.3.

2. To evaluate total uncertainties induced by nuclear data in the integral parameters, and investigate the contributions to their uncertainties.

Integral parameters:

Criticality (k_{eff}) and **LBE void reactivity**

Calculation Conditions

Reference ADS

- Geometry: 2-dimensional R-Z model
- Components: (MA+Pu)N + ZrN
  (k_{eff} is adjusted to 0.97 with JENDL-3.3)
- Void-reactivity calculation:
  LBE in MA core is voided

Nuclear Data Library

- JENDL-4.0 cross-section/covariance data
  (processed to a 70-energy-group structure with NJOY/ERRORJ)

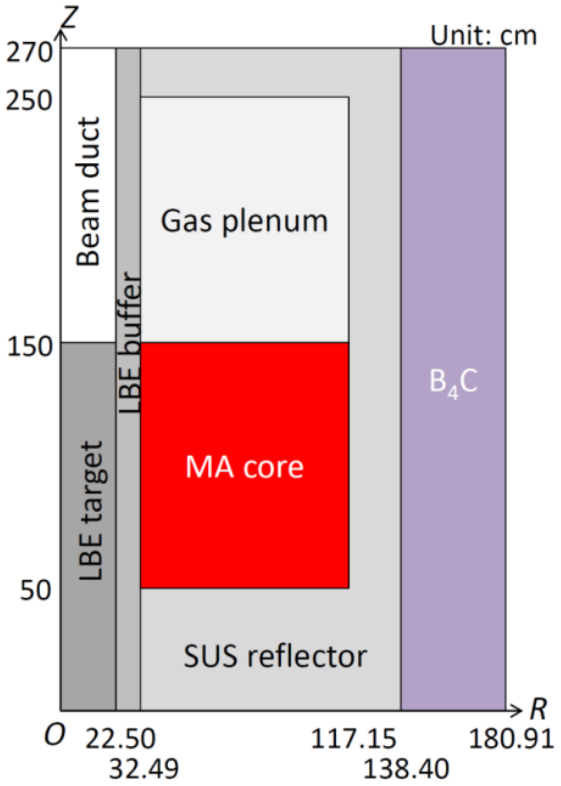


Fig. Geometry of the ADS

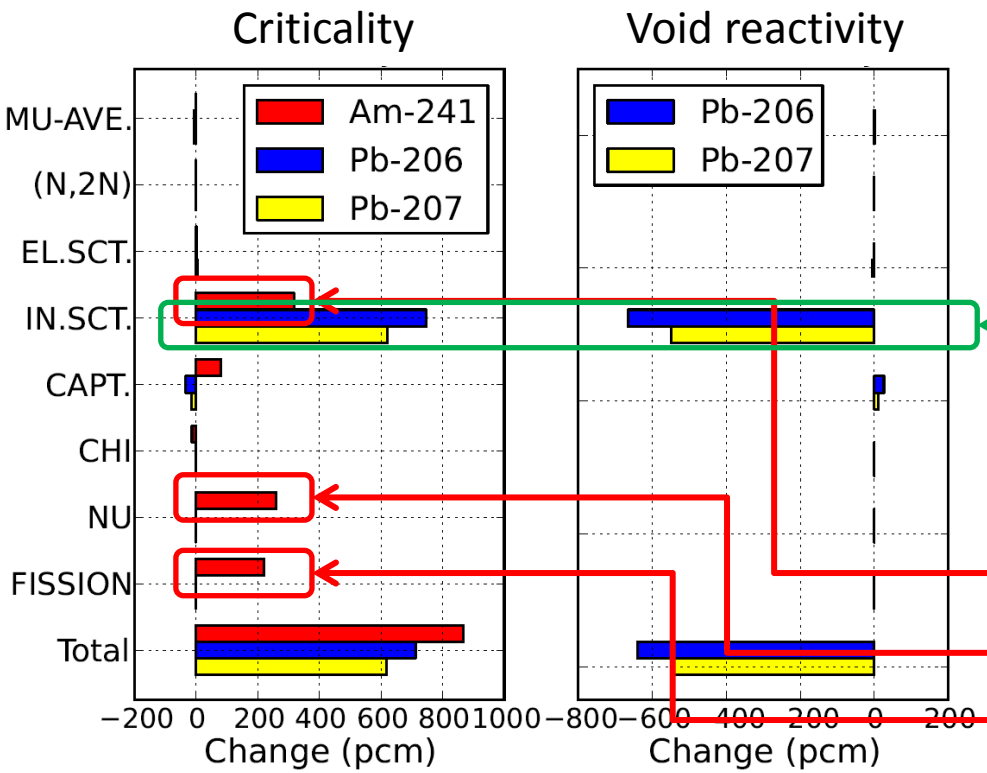
Analysis Method

- Effective cross section: SLAROM-UF
- keff and flux: CITATION (deterministic, diffusion theory)

Cause of Differences from JENDL-3.3

Table Integral parameters and their nuclear-data-induced uncertainties

	JENDL-4.0	JENDL-3.3	Difference from J33
Criticality (k_{eff})	**1.000** (1.04%)	**0.971**	2.99%
LBE void reactivity (pcm)	**3875** (9.44%)	**5331**	-27.31%



Main causes of differences

Pb-206, -207
- **Inelastic scattering**

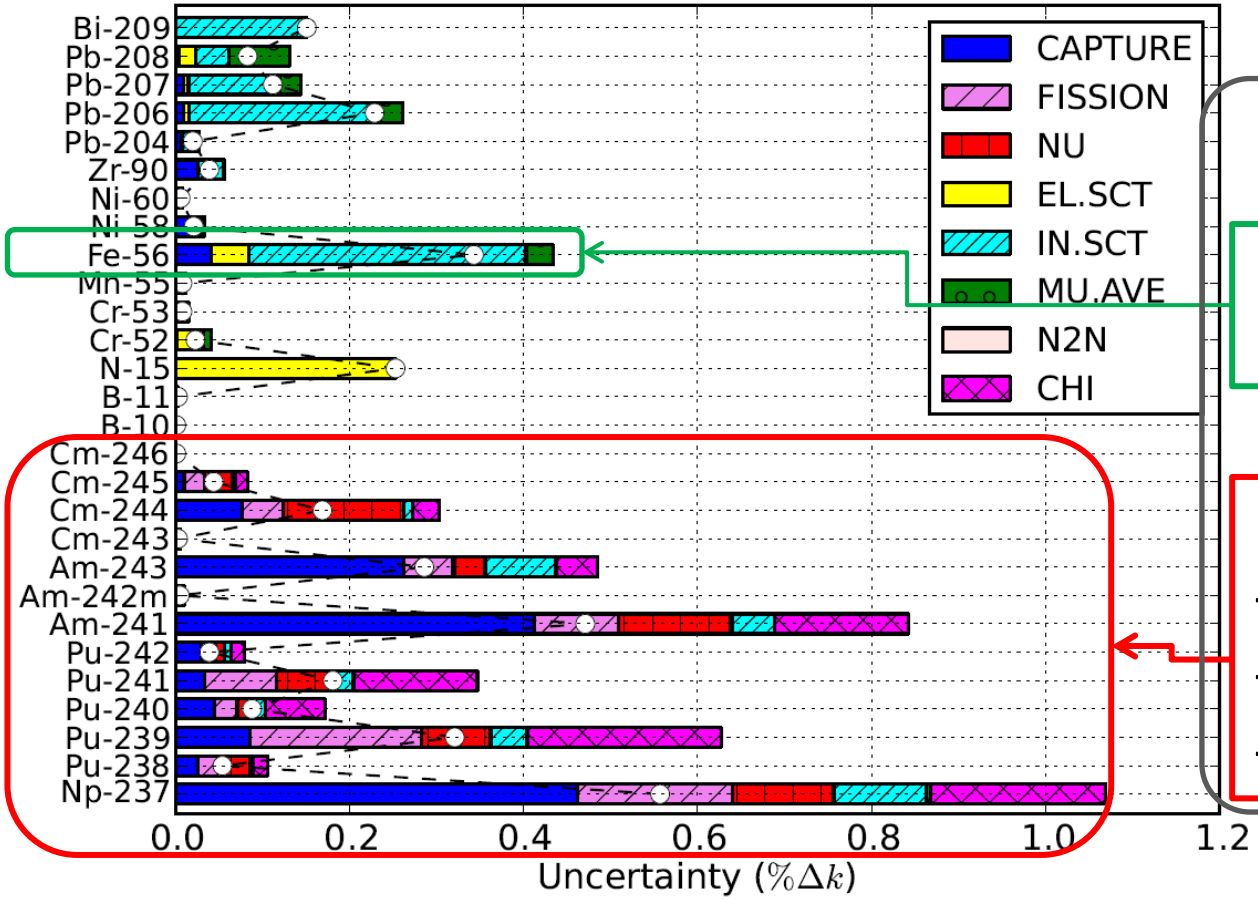
Am-241
- **Inelastic scattering**
- **ν value**
- **Fission cross section**

Fig. Major contributors to the differences*

*H. Iwamoto, JAEA-Review,2011-036 (2012)

Criticality Uncertainty

Total uncertainty: 1.04%Δk



Major contributions to uncertainty

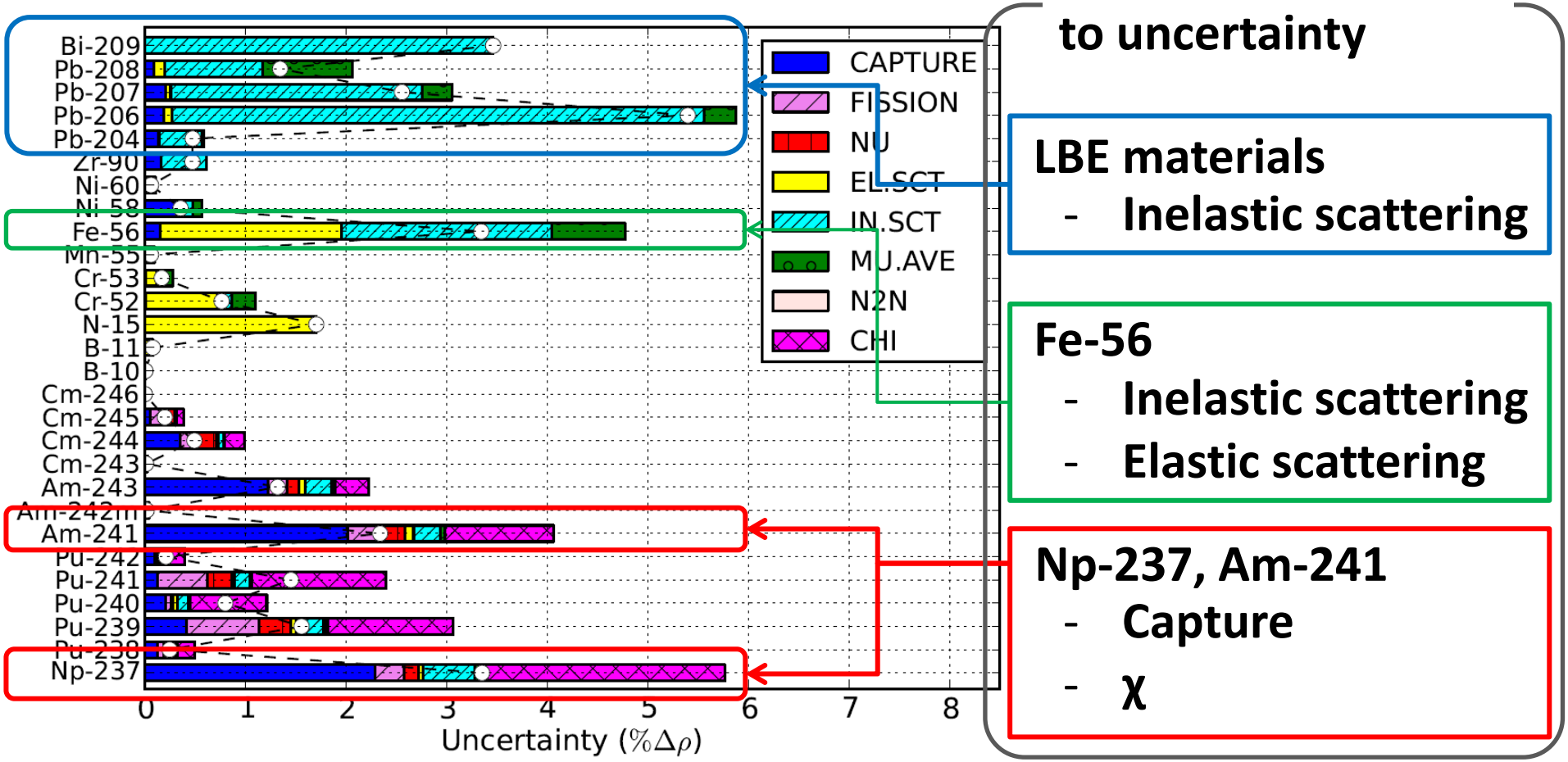
Fe-56
- **Inelastic scattering**

TRU
- **Capture**
- **Fission**
- **χ , ν**

Fig. Breakdown of criticality uncertainty

Void Reactivity Uncertainty

Total uncertainty: 9.44%Δρ



Major contributions to uncertainty

LBE materials
- **Inelastic scattering**

Fe-56
- **Inelastic scattering**
- **Elastic scattering**

Np-237, Am-241
- **Capture**
- **χ**

Fig. Breakdown of void-reactivity uncertainty

Important Reaction Parameters

Causes of differences from JENDL-3.3

- ^{206,207}Pb
  - Inelastic scattering
- ^{241}Am
  - Inelastic scattering
  - ν value
  - Fission cross section

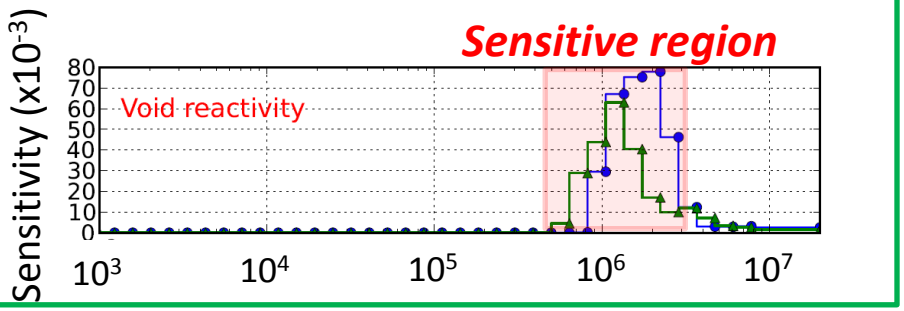
Contributions to uncertainties

- TRU(^{237}Np,^{241,243}Am,^{239,241}Pu,^{244}Cm)
  - Capture
  - Fission related parameters
- LBE (Pb and ^{209}Bi)
  - Inelastic scattering
- Fe-56
  - Inelastic scattering

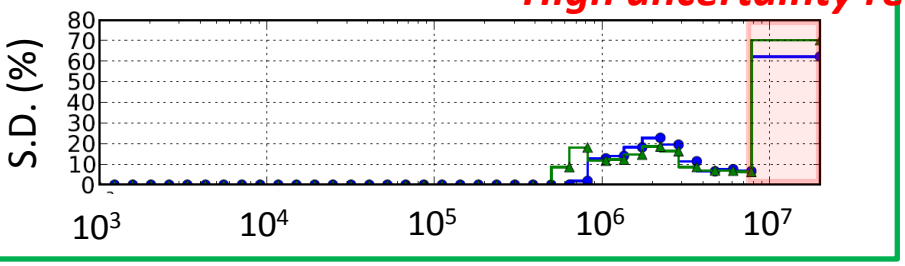
- ^{206,207}Pb inelastic scattering cross section
- ^{237}Np fission neutron spectrum
- ^{241}Am capture cross section

^{206,207}Pb Inelastic Scattering

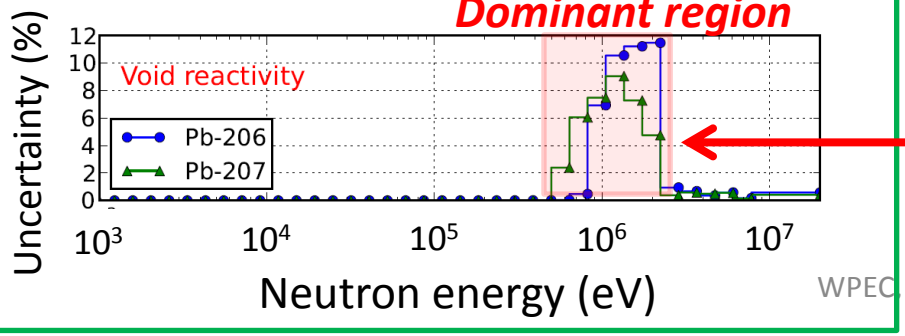
➢ **Sensitivity coefficients**



➢ **Covariance data (1σS.D.)**



➢ **Energy breakdown of uncertainties**



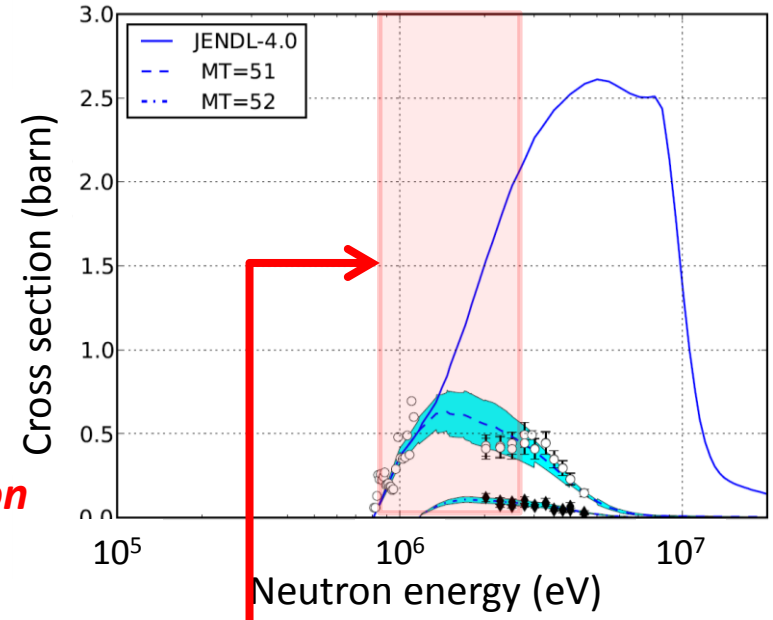
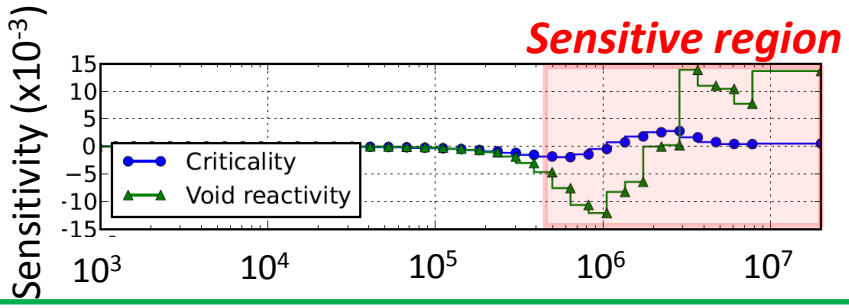


Fig. ^{206}Pb inelastic scattering cross section

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

^{237}Np Fission Neutron Spectrum

➢ **Sensitivity coefficients**



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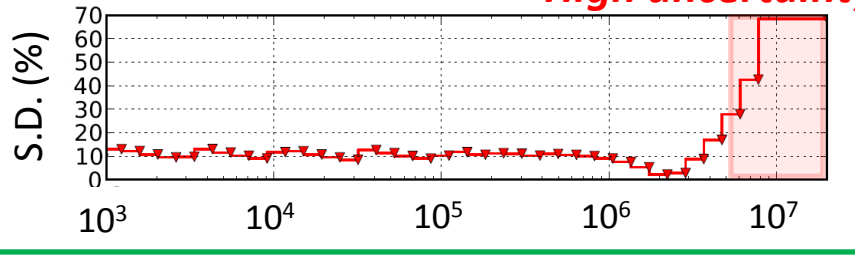

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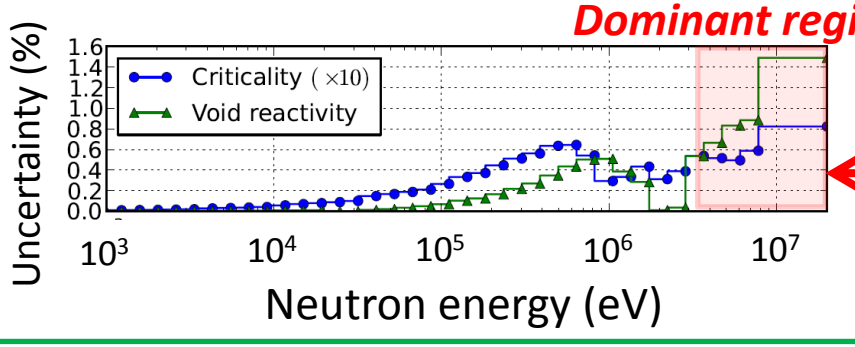


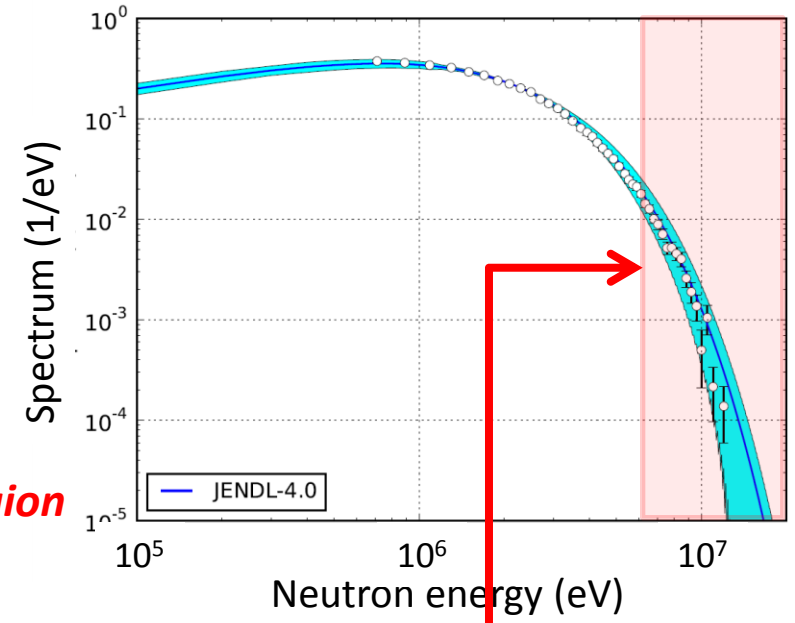
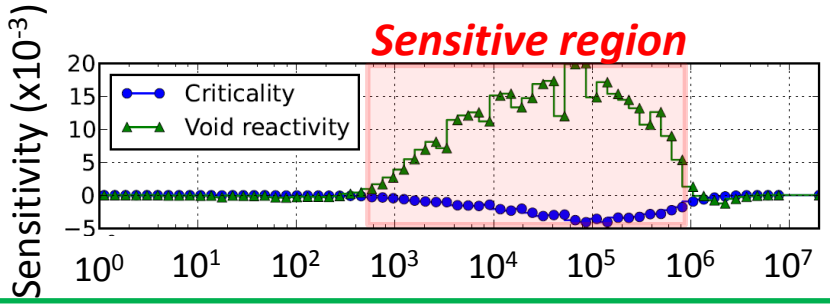


Fig. ^{237}Np fission neutron spectrum
(n(0.5 MeV) + ^{237}Np)

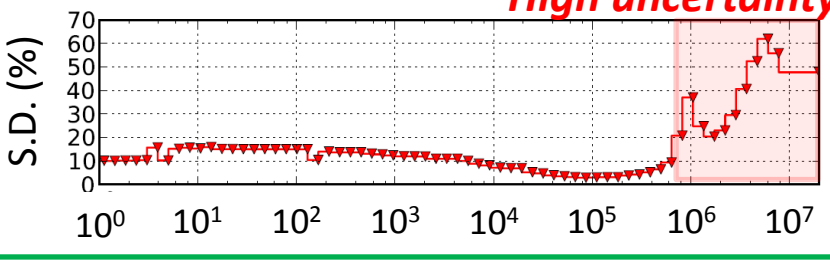
Nuclear-data evaluation in this region (above 5 MeV) affects the uncertainties in the integral parameters!

^{241}Am Capture Cross Section

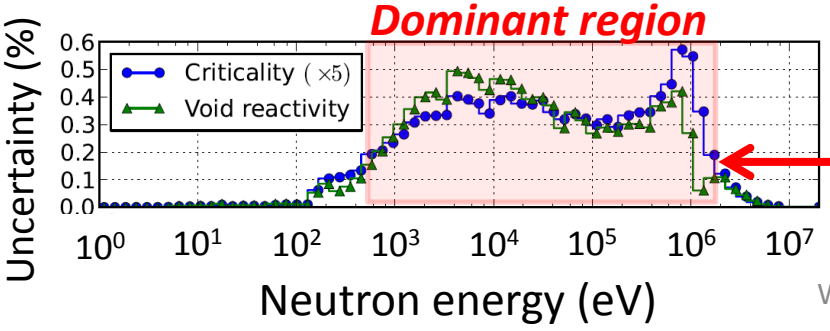
- **Sensitivity coefficients**



- **Covariance data (1σ S.D.)**



- **Energy breakdown of uncertainties**



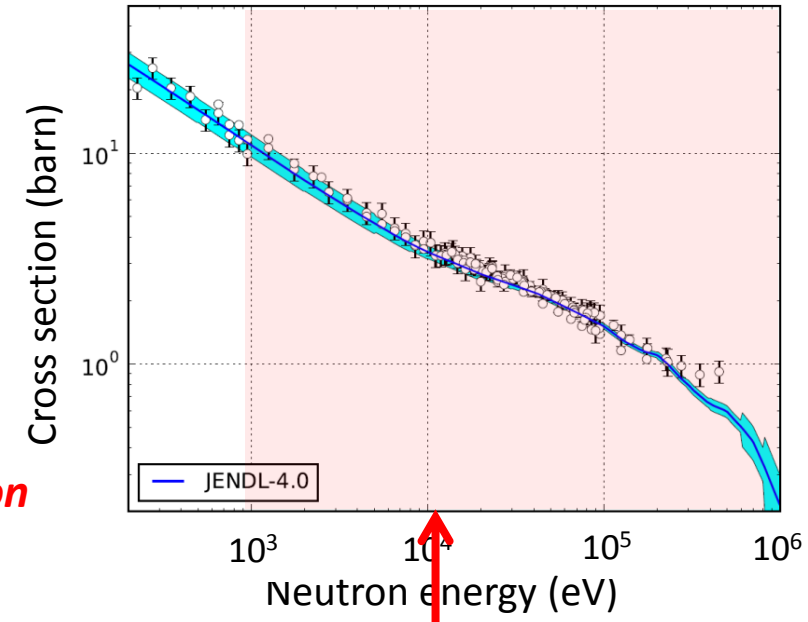


Fig. ^{241}Am capture cross section

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

Summary (1/3)

- The integral parameters were calculated with JENDL-4.0.

	JENDL-4.0	JENDL-3.3	Difference
Criticality (k_{eff})	**1.000** (1.04%)	**0.971**	2.99%
LBE void reactivity (pcm)	**3875** (9.44%)	**5331**	-27.31%

- The differences from the JENDL-3.3 are due to the changes in

✓ **^{206,207}Pb**
- **Inelastic scattering**

✓ **^{241}Am**
- **Inelastic scattering**
- **Fission-related parameters**

- Main contributions to the uncertainties in the reactor physics parameters are

✓ **TRU**
- **Capture**
- **Fission-related parameters**

✓ **LBE, Fe**
- **Inelastic scattering**

Summary (2/3)

- Energy regions important to the reduction of the uncertainty of the integral parameters are

  e.g.

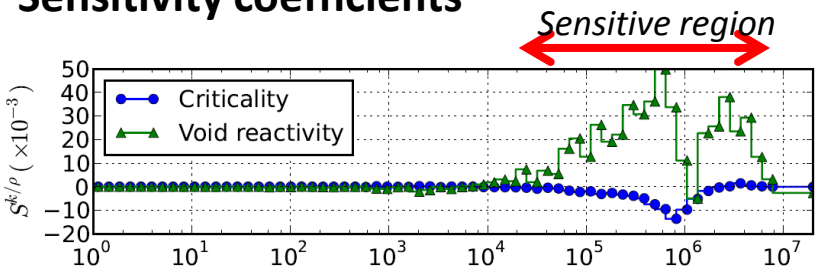
  - ✓ **^{206,207}Pb inelastic cross section:**
    From threshold energy to ~3 MeV
  - ✓ **^{237}Np fission neutron spectrum:**
    Above 5 MeV
  - ✓ **^{241}Am capture cross section:**
    From 1 keV to 1 MeV

Summary (3/3)

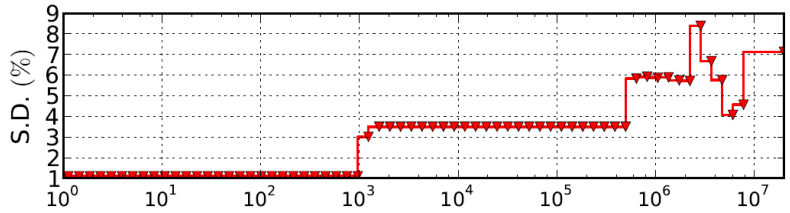
- Requirements on the nuclear data evaluation are investigated based on the covariance data in JENDL-4.0.
- Some reactions and energy region are specified as causes of uncertainties.
- Integral experiments using critical assemblies:
  - ✓ Pb and Bi void reactivity in KUCA.
  - ✓ Partial mock-up of MA fuel in TEF-P planed in J-PARC.

^{15}N elastic scattering

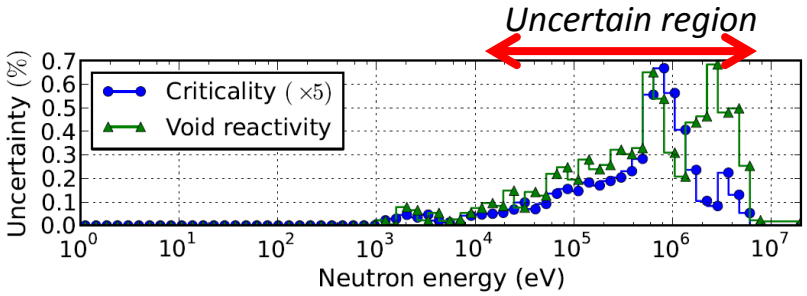
- **Sensitivity coefficients**



- **Covariance data (1σ standard deviation)**



- **Energy breakdown of uncertainties**



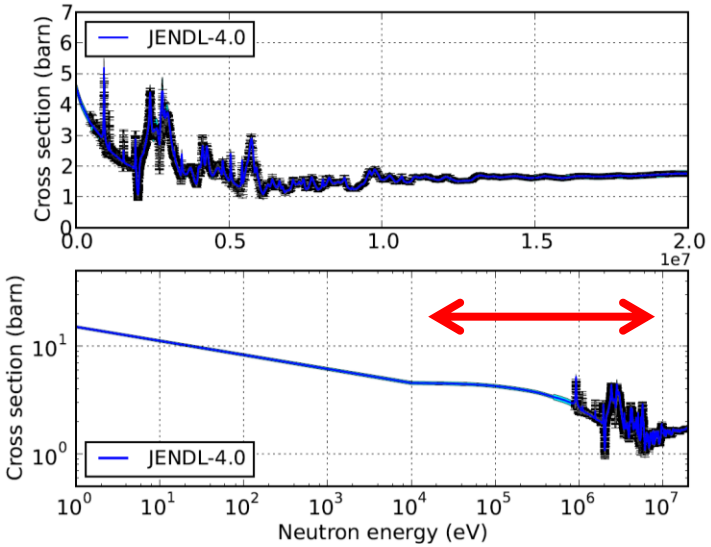
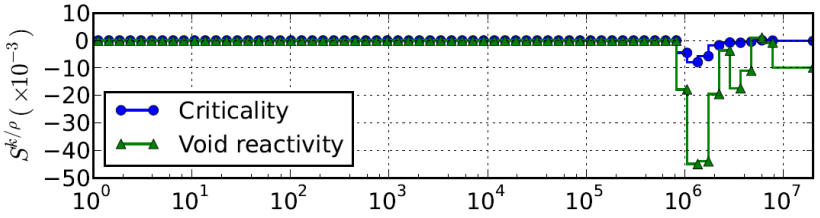


Fig. ^{15}N *total* cross section

^{56}Fe inelastic scattering

- **Sensitivity coefficients**



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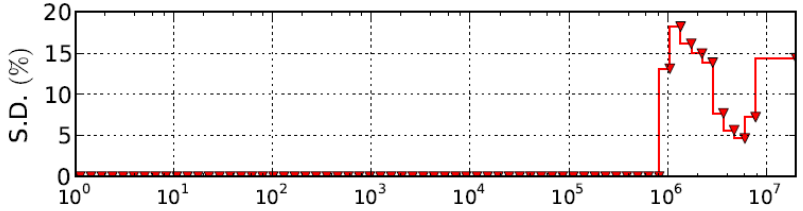

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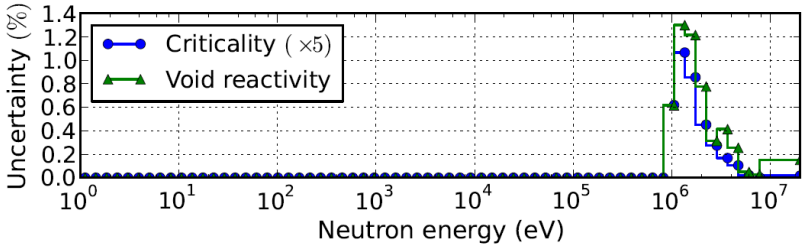


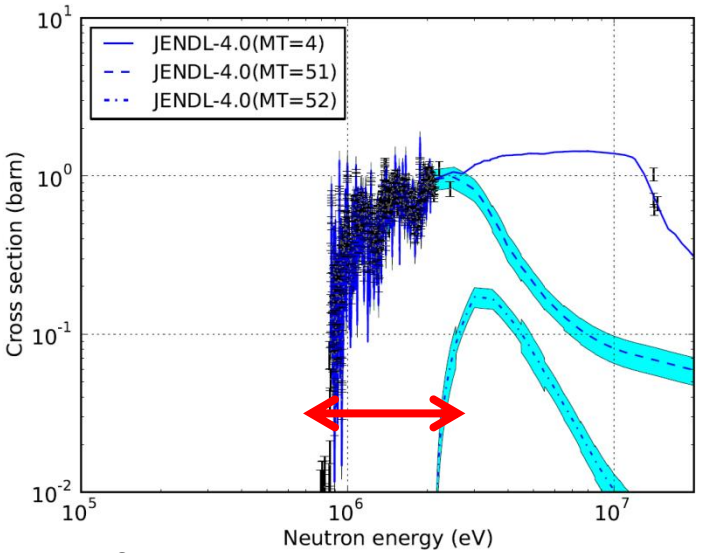
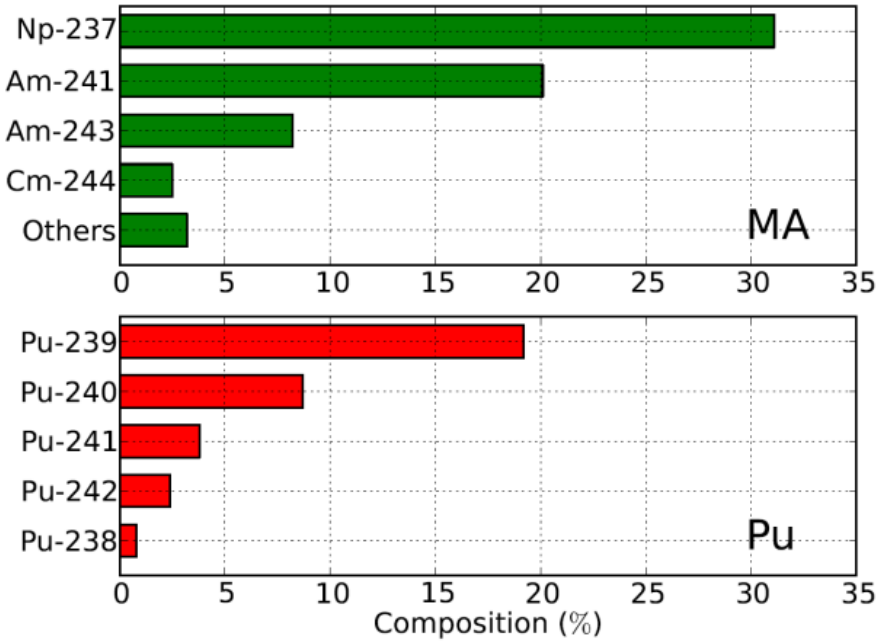


Fig. ^{56}Fe inelastic scattering cross section


Np-237
Am-241
Am-243
Cm-244
Others
MA
0
5
10
15
20
25
30
35
Pu-239
Pu-240
Pu-241
Pu-242
Pu-238
Pu
0
5
10
15
20
25
30
35
Composition (%)