Thorium Core Characteristics

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Thorium Core Characteristics

Thorium-loaded core characteristics depends on

Core type LWR(BWR, PWR), FR, MSR, …

different neutron spectrum field

Fuel composition $(Th,U)O_2$, $(Th,Pu)O_2$, …

different thermal/mechanical property

Strategy Open/closed cycle, Partial/Full core loading, …

different target
(conversion, reprocessing(?), …)

Thorium-loaded core characteristics can be evaluated by

Neutronic parameters

nuclear reaction cross section
capture, fission, ν, $\eta(=\nu\sigma_f/\sigma_a)$, …
delayed neutron fraction : β,
decay chain,
decay constant : λ,
} fixed value

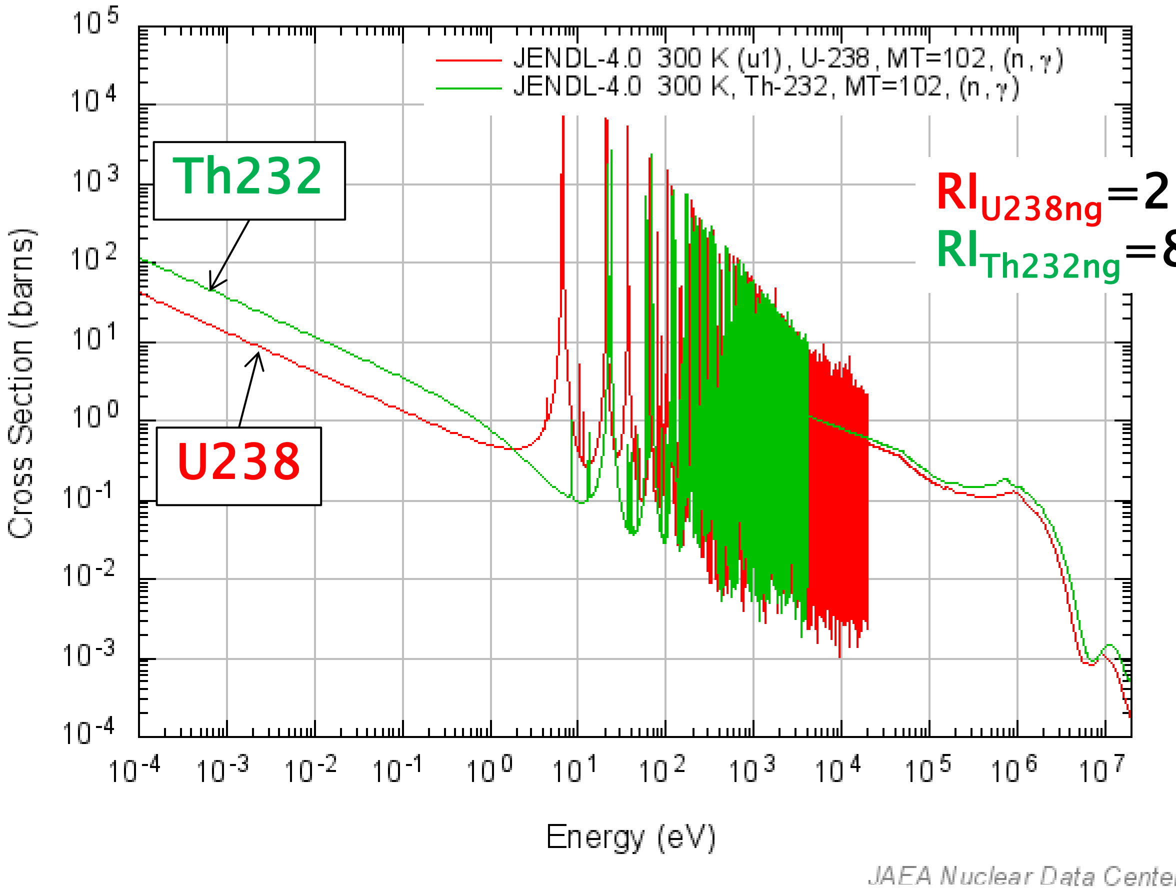
fission yield,
generation time : Λ
} dependence on core type, etc.

Material parameters

thermal/mechanical property
thermal conductivity,
density (of sintered fuel),
O/M,
porosity, …

Cross section & Resonance integral

Resonance Integral : RI $= \int_{0.5eV}^{10MeV} \sigma(E)\frac{1}{E}dE$



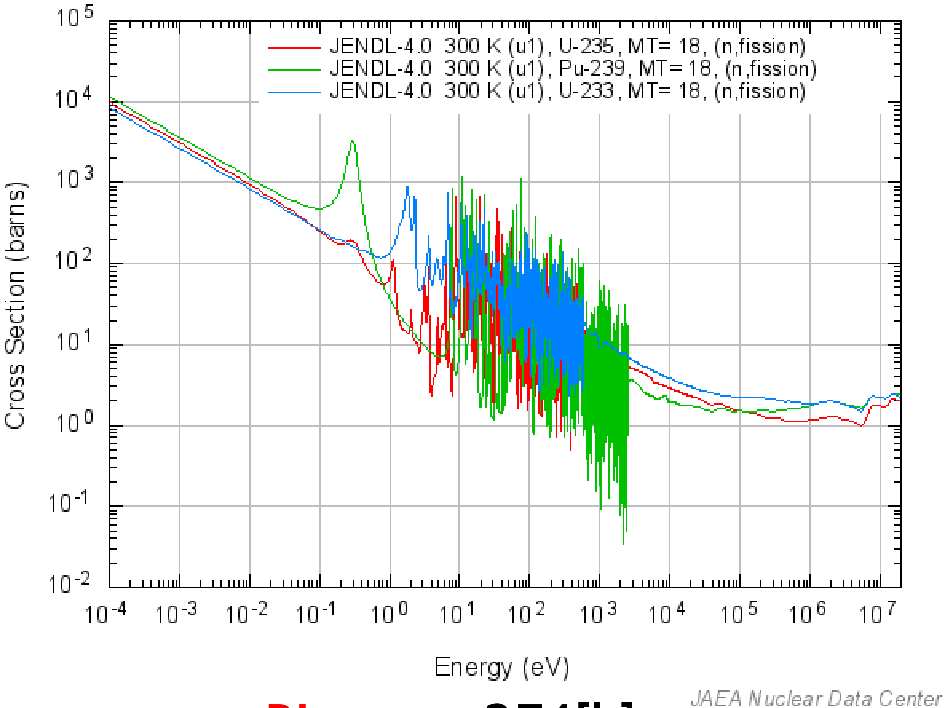
RI_{U238ng}=276[b]
$RI_{Th232ng}$=84[b]

Lower RI & higher 1st resonance energy ⇒ doppler reactivity,
Higher cross section @ thermal energy range ⇒ CR/Boron worth,

http://wwwndc.jaea.go.jp/ENDF_Graph/

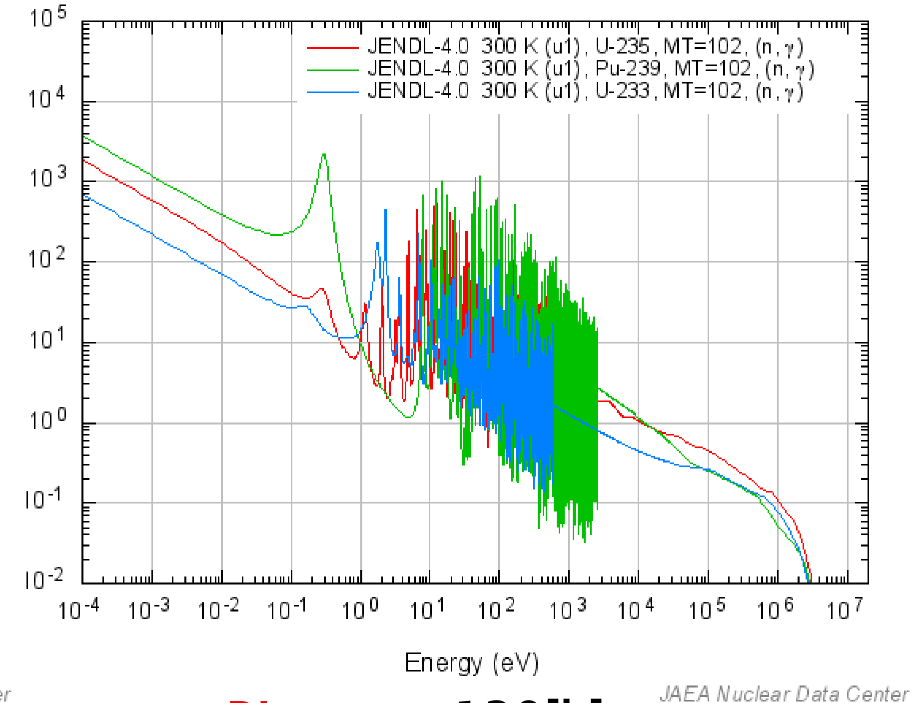
Cross section & Resonance integral

U235, Pu239, U233 (n,fission)



RI_{U235nf} =274[b]
$RI_{Pu239nf}$=301[b]
RI_{U233nf} =775[b]

U235, Pu239, U233 (n,g)



RI_{U235ng} =139[b]
$RI_{Pu239ng}$=180[b]
RI_{U233ng} =139[b]

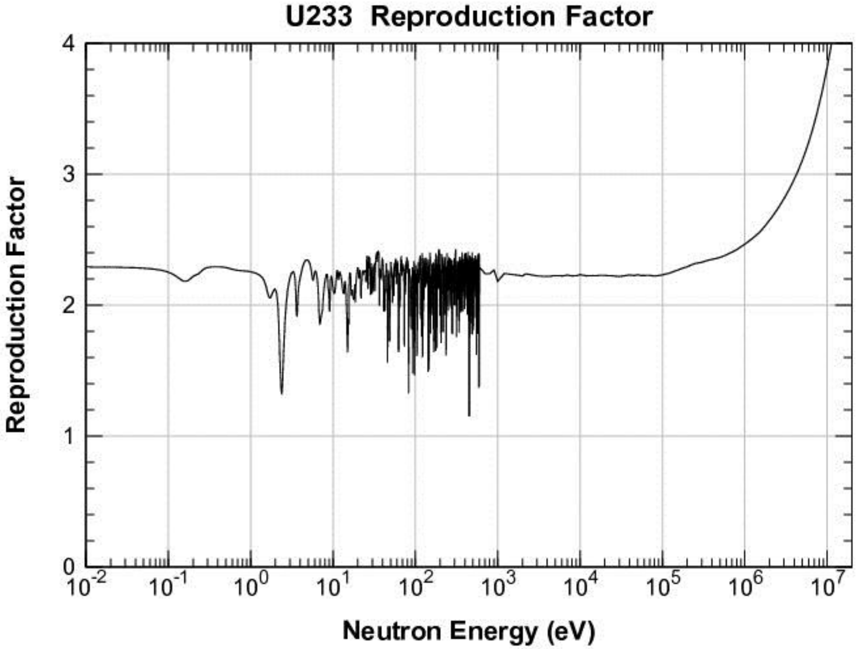
At low energy range (<0.1eV),

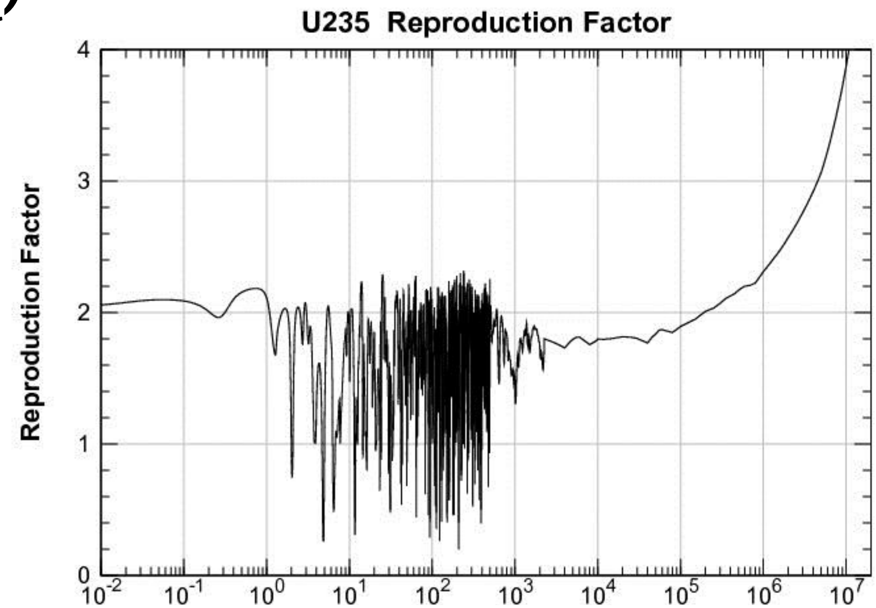
σ_f : U235 ≈ Pu239 ≈ U233

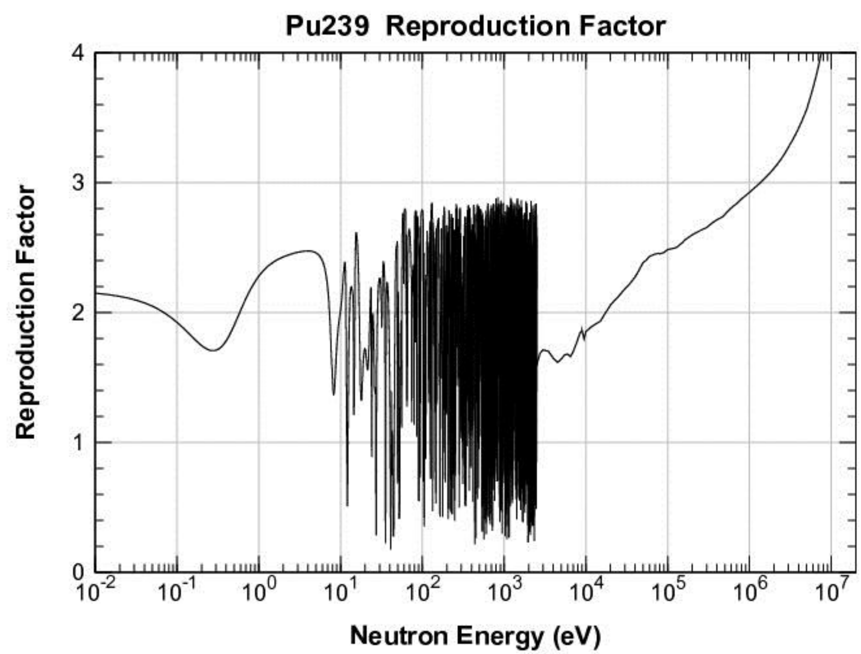
σ_c : Pu239 > U235 > U233

http://wwwndc.jaea.go.jp/ENDF_Graph/

Reproduction factor ($\nu\sigma_f/\sigma_a$)





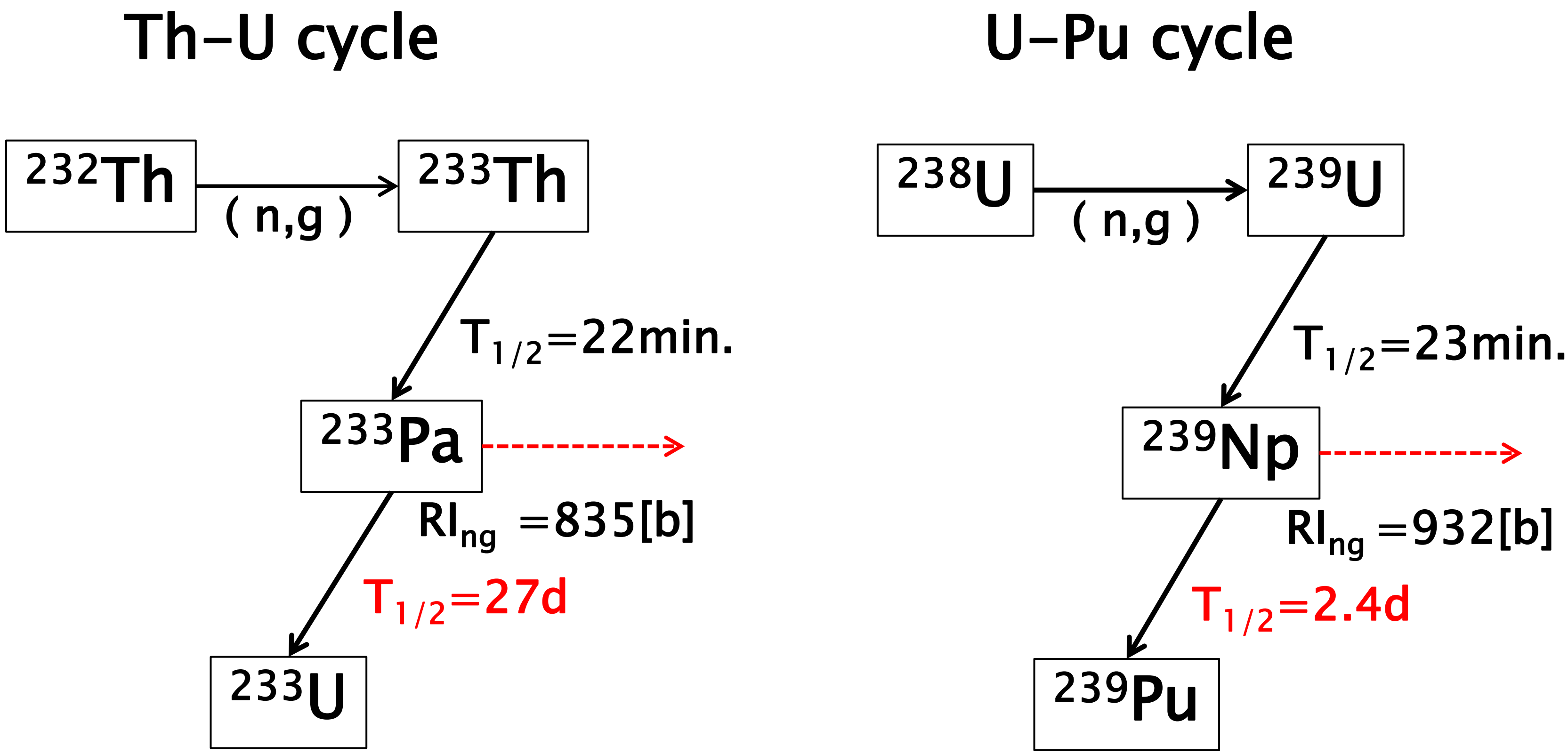


Higher reproduction factor of U233 >2.0 other than reso. energy range

⇩

Conversion/breeding ratio
Depletion (burnup property)

Nuclear transmutation from Th232/U238



Longer half-life of ^{233}Pa ⇒ conversion ratio (depends on power)
(n,g) reaction of $^{233}Pa/^{239}Np$

Delayed neutron fraction : β

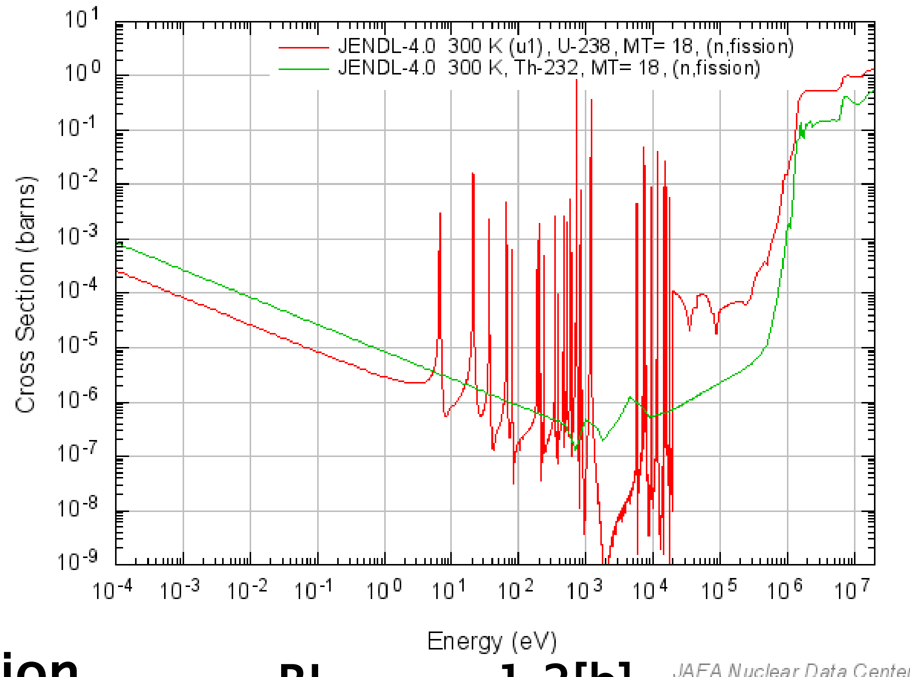
	β	ν d
U233	0.0027	0.0074
U235	0.0064	0.0167
Pu239	0.0020	0.0065
Th232	0.0203	0.0527
U238	0.0148	0.0460

Smaller fraction of U233
Larger fraction of Th232

⇓

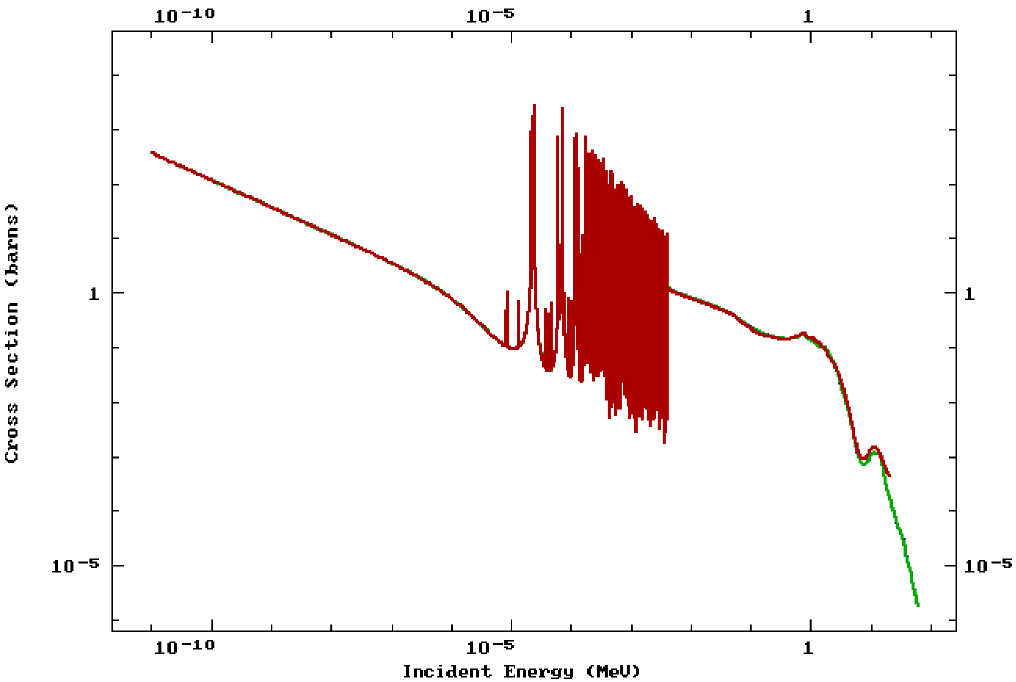
β_{eff} : Effective delayed neutron fraction,
Neutron kinetics/dynamics

U238, Th232 (n,f)



RI_{U238nf} =1.2[b]
$RI_{Th232nf}$=0.37[b]

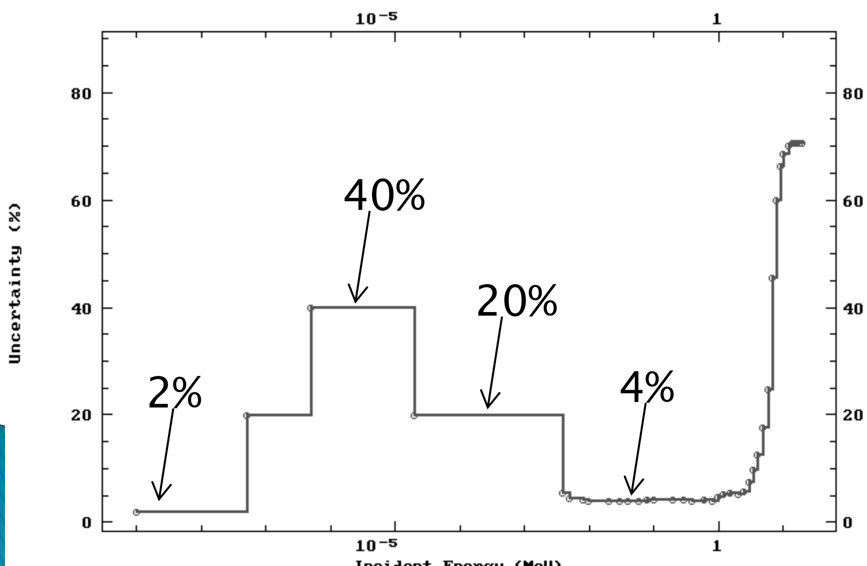
Uncertainty of Cross section



Comparison of Th232 (n,g) Xsec.
(ENDF/B-VII.1, JEFF-3.2, JENDL-4.0)

- 1) ENDF/B-VII.1: TH-232(N,G)TH-233
- 2) JEFF-3.2: TH-232(N,G)TH-233
- 3) JENDL-4.0: TH-232(N,G)TH-233

Discrepancy is trivial.



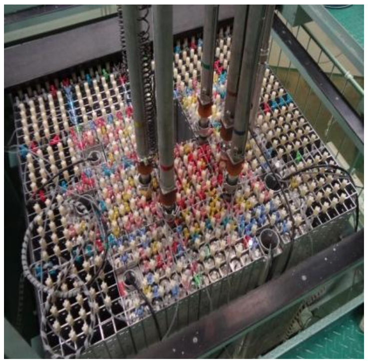
Although,
Uncertainty (1σ, JENDL-4.0) is
4% unresolved reso. reg.,
20% resolved reso. reg.,
2% thermal energy range.
⇒ uncertainty in core property

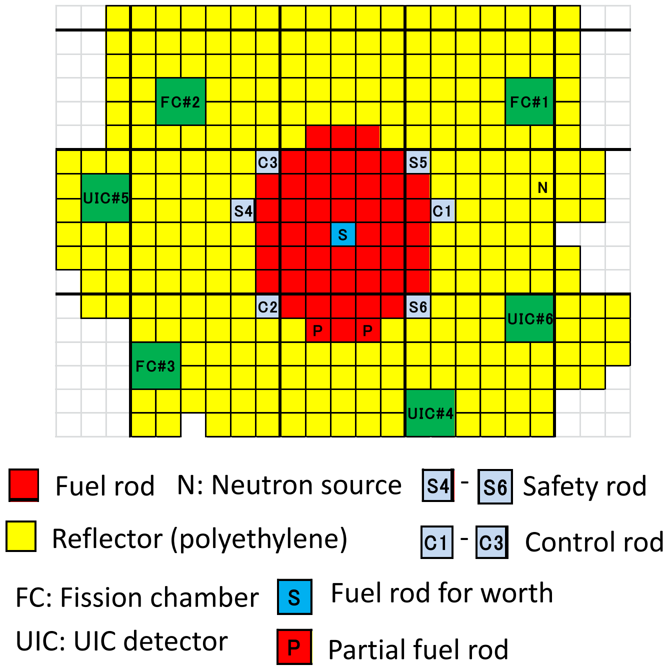
https://www-nds.iaea.org/exfor/endf.htm

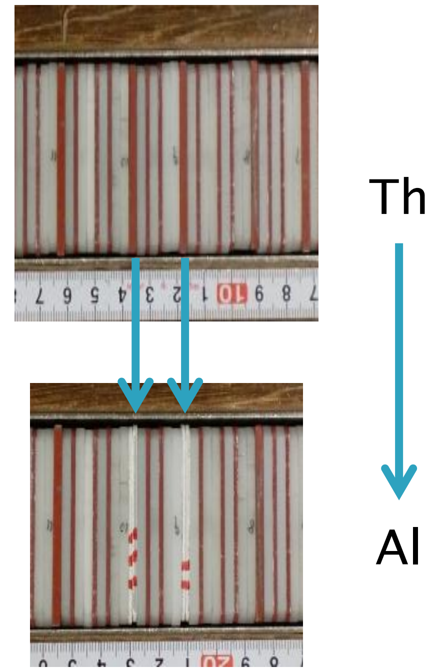
Validation of Cross section

Analysis of Post Irradiation Experiment (PIE)

Analysis of Thorium replacement worth measured at critical experiment facility (at KUCA, 2011-2013 with Kyoto Univ., Tokai Univ., Osaka Univ.,)





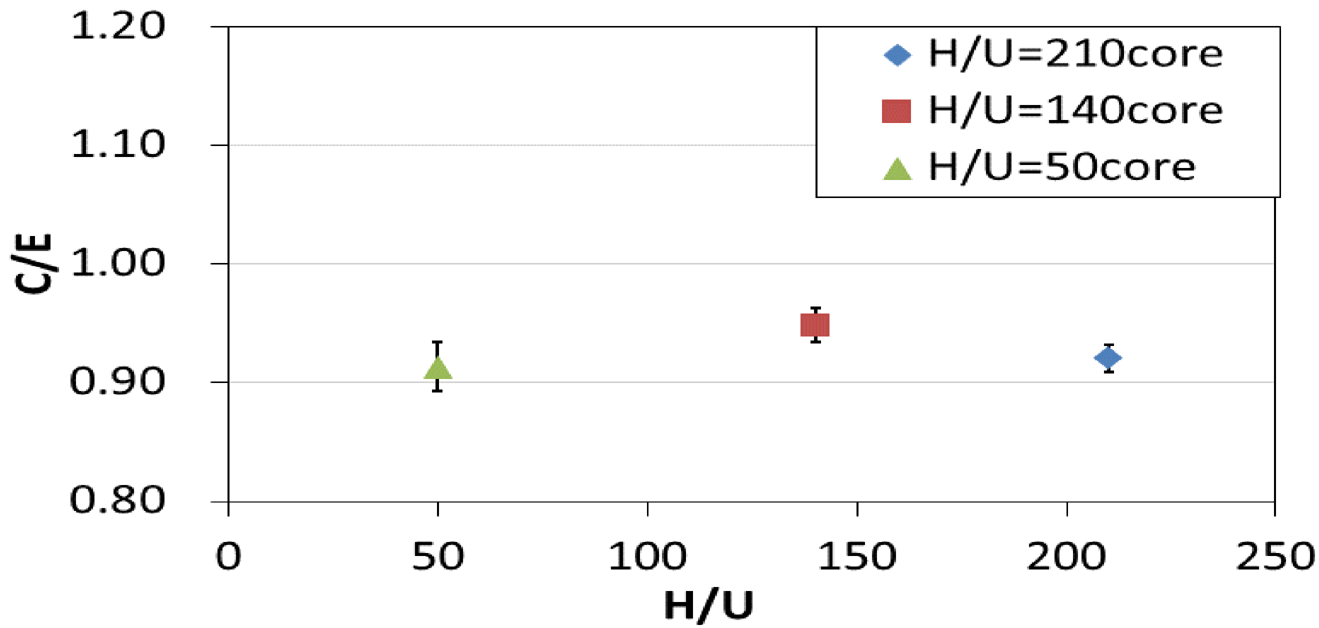


Th-plate → Al-plate causes the change in excess reactivity.
(Thorium replacement worth)

H/U (Hydrogen/U235) is 50, 140 and 210, by changing the arrangement of fuel cell, to obtain different neutron spectrum field.

Analysis of Th-replacement worth measured at KUCA

Analysis : continuous energy MC in 3D as-built model.
(MVP-2.0, JENDL-4.0, 1billion histories)

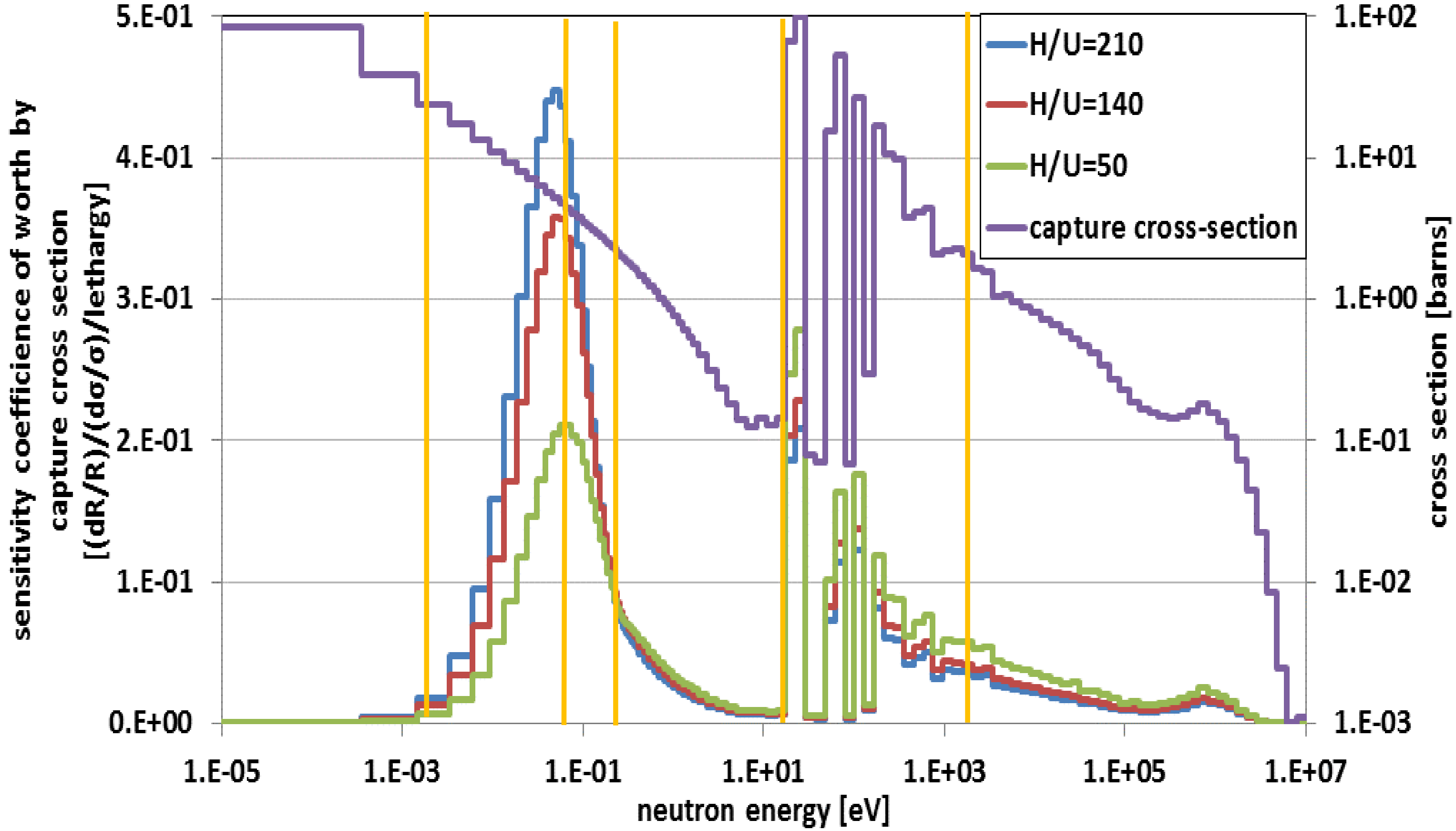


(1σ)

Underestimation (5-10%) of Th-replacement worth for all cases
⇒ underestimation of Th-(n,g) Xsec. is expected.
C/E is the smallest for the case of H/U=50.

Sensitivity Coefficient (SC) of Th-replacement worth

SC is different among three cases.



Energy range is separated so as to discuss the contribution to the underestimation by considering Xsec. uncertainty (JENDL-4.0).

Uncertainty of Th-replacement worth (from Th232 (n,g) Xsec. Uncertainty)

$$\left[\sum_{nuc,reac,energy}\left(SC_{nuc,reac,energy}\times \boxed{Var}\times SC^{T}_{nuc,reac,energy}\right)\right]^{1/2}$$

X.sec. covariance

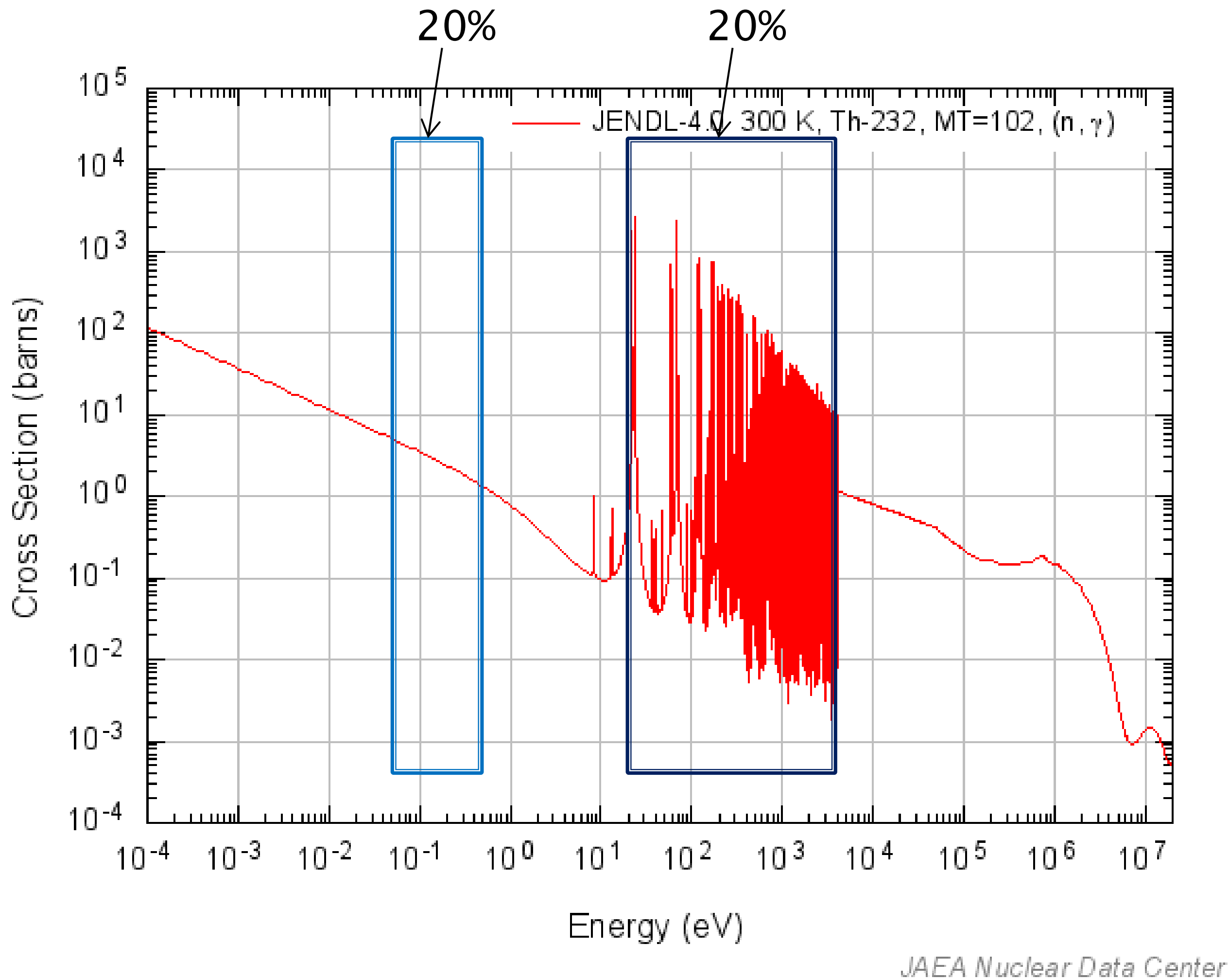
Energy breakdown of uncertainty of the worth

core H/U	energy range[eV]						
	1.00E−5～1.47E−3	1.47E−3～5.42E−2	5.42E−2～5.32E−1	5.32E−1～2.26E+1	2.26E+1～4.31E+3	4.31E+3～1.00E+7	total
210	0.012	0.021	0.086	0.033	0.059	0.014	0.108
140	0.015	0.022	0.089	0.037	0.075	0.018	0.116
50	0.021	0.024	0.065	0.042	0.087	0.024	0.106

Dominant uncertainty comes from 0.05～0.5eV, and 23eV～4keV

This range is likely to be underestimated by considering the C/E tendency on H/U

Total uncertainty is more than 10%



Further experiment at different neutron spectrum field is desirable, to ascertain the detailed underestimation of Th-replacement worth.

http://wwwndc.jaea.go.jp/ENDF_Graph/

Conclusions

Th-loaded core characteristics
have been evaluated for many types of reactors,
depend on neutron spectrum field, fuel composition, strategy.

Th-loaded core characteristics
analysis results may have much more uncertainty than expected,
although three major libraries show good agreement,

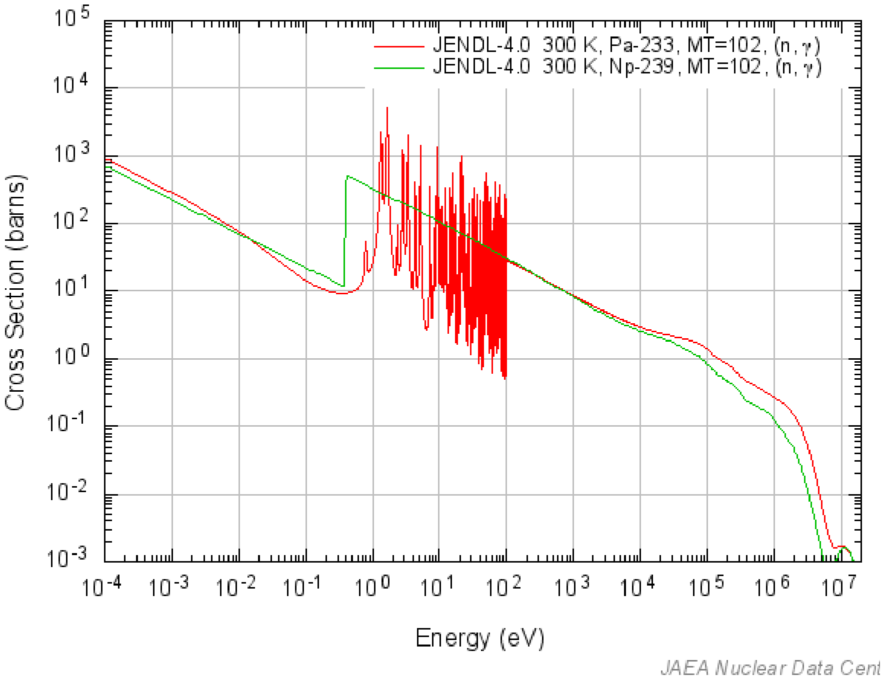
Further experimental results (PIE, Th-worth measurement@KUCA, …)
are desirable to enhance the accuracy of Thorium Xsec.
for better consideration of Th-loaded core performance.

Thank you for your attention.

Is there any questions?

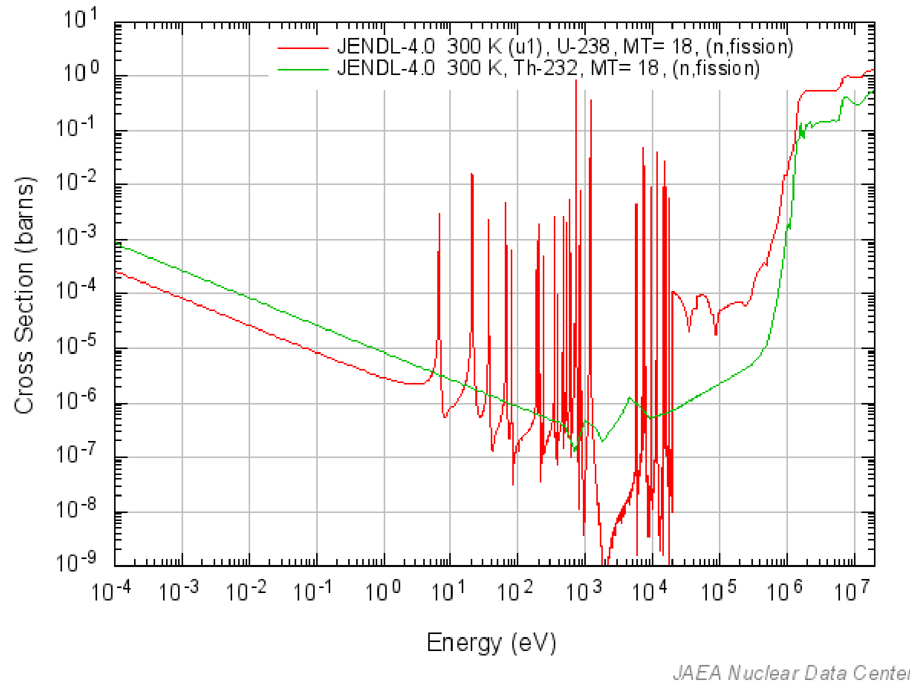
Cross section & Resonance Integral

Pa233, Np239 (n,g)



$RI_{Pa233ng}$ =835[b]
$RI_{Np239ng}$ =932[b]

U238, Th232 (n,f)



RI_{U238nf} =1.2[b]
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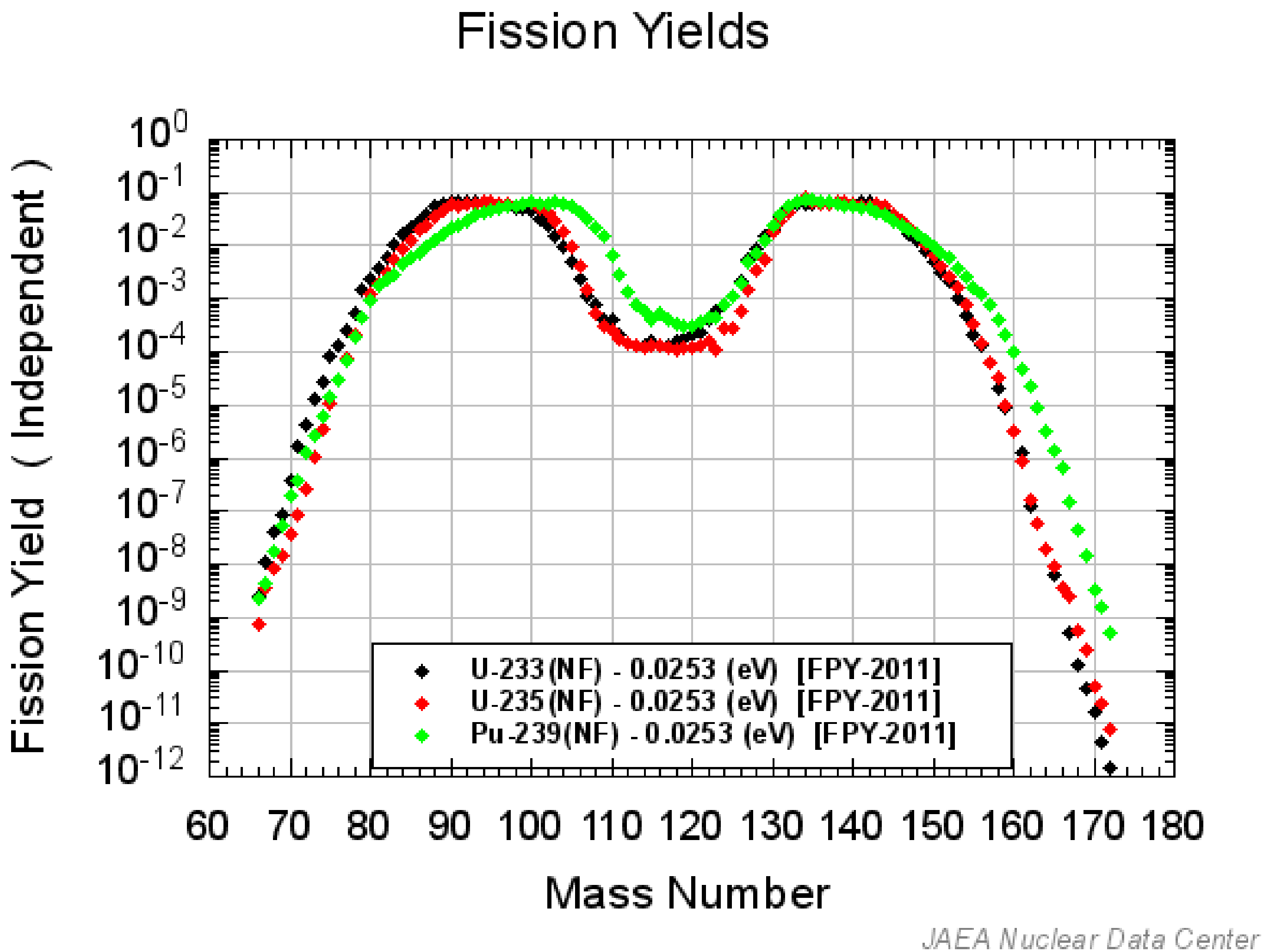
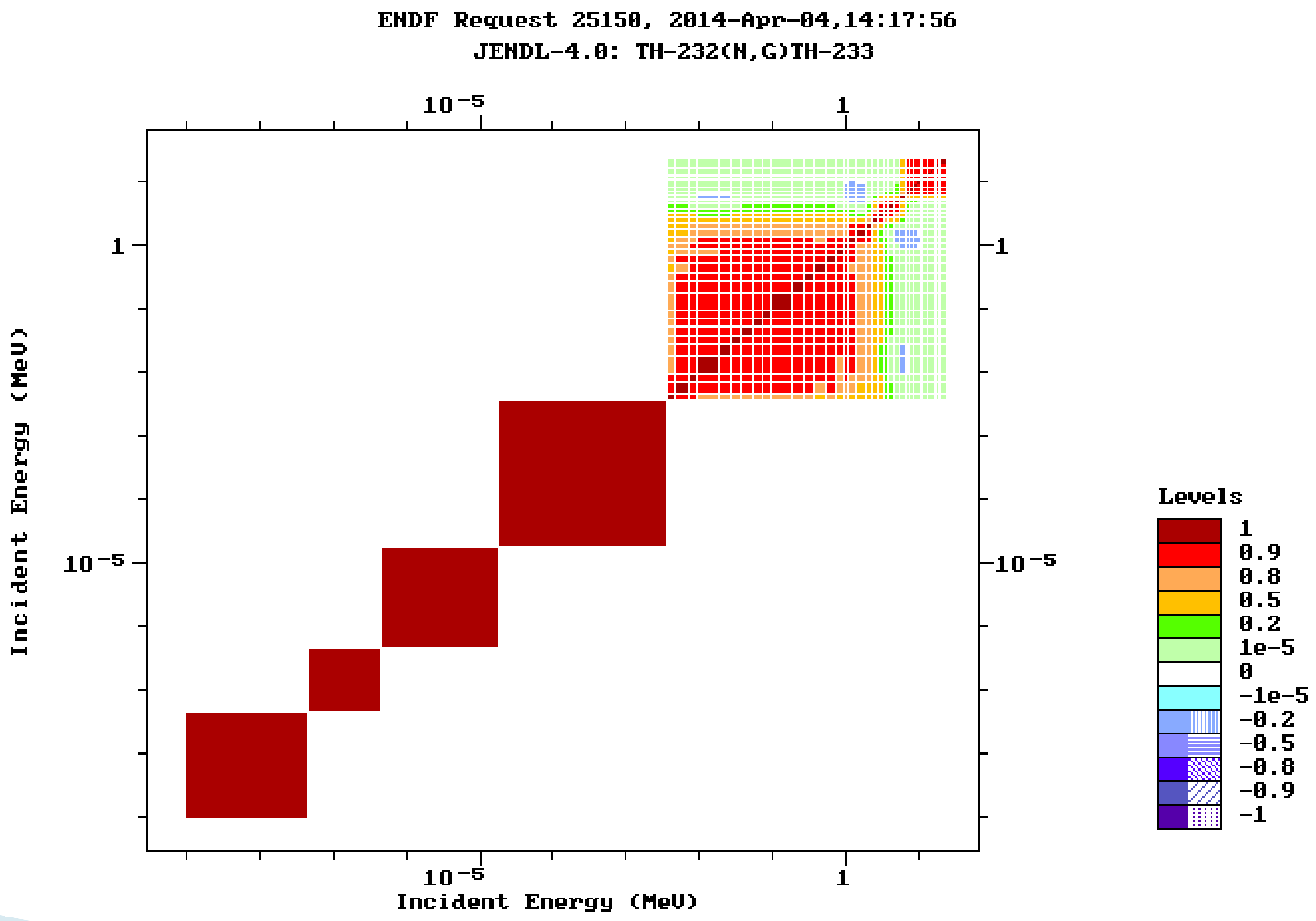
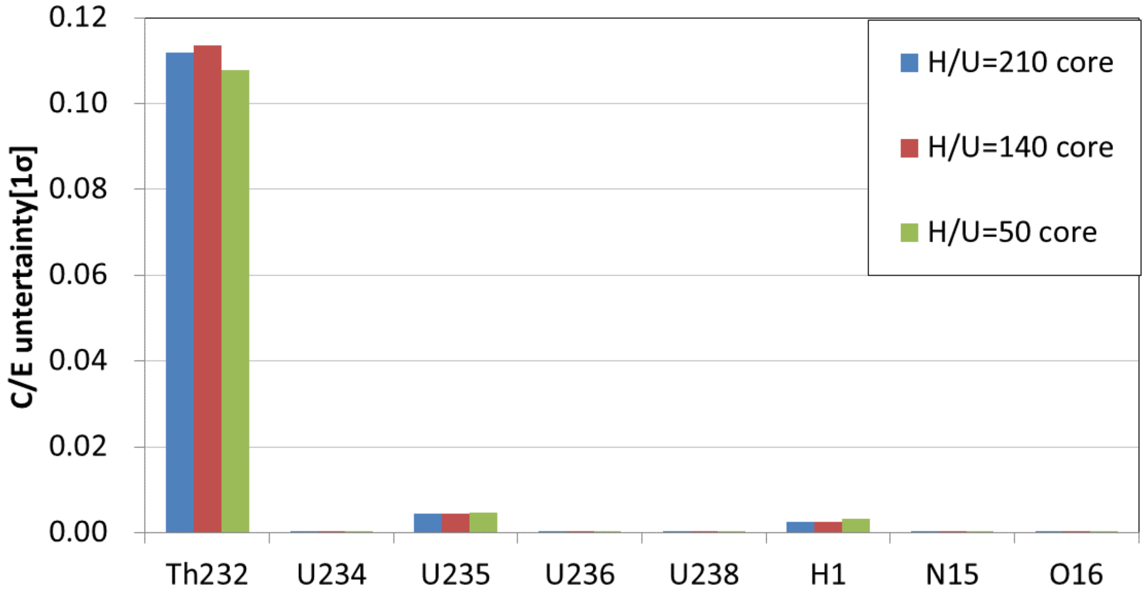
Resonance Integral : RI = $\int_{0.5eV}^{10MeV} \sigma(E)\frac{1}{E}dE$

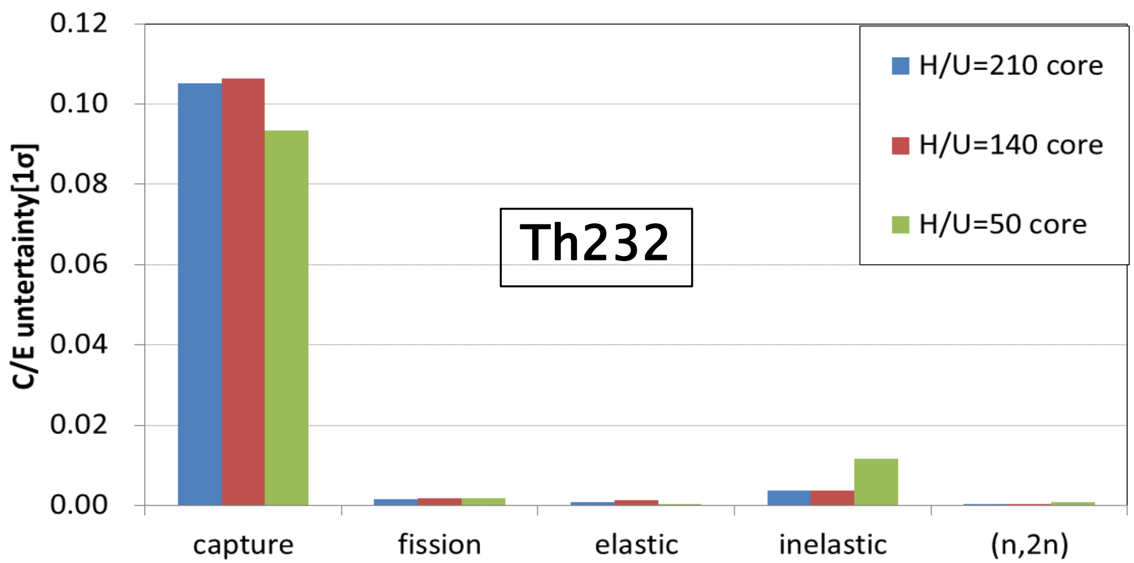


http://wwwndc.jaea.go.jp/cgi-bin/FPYfig

Correlations of Th232 (n,g) Xsec.







Uncertainty of the worth mainly comes from Th232 (n,g).