# PRELIMINARY RESULTS OF THE ZPR 6-7 AND ZPR-9 SENSITIVITY AND UNCERTAINTY ANALYSIS

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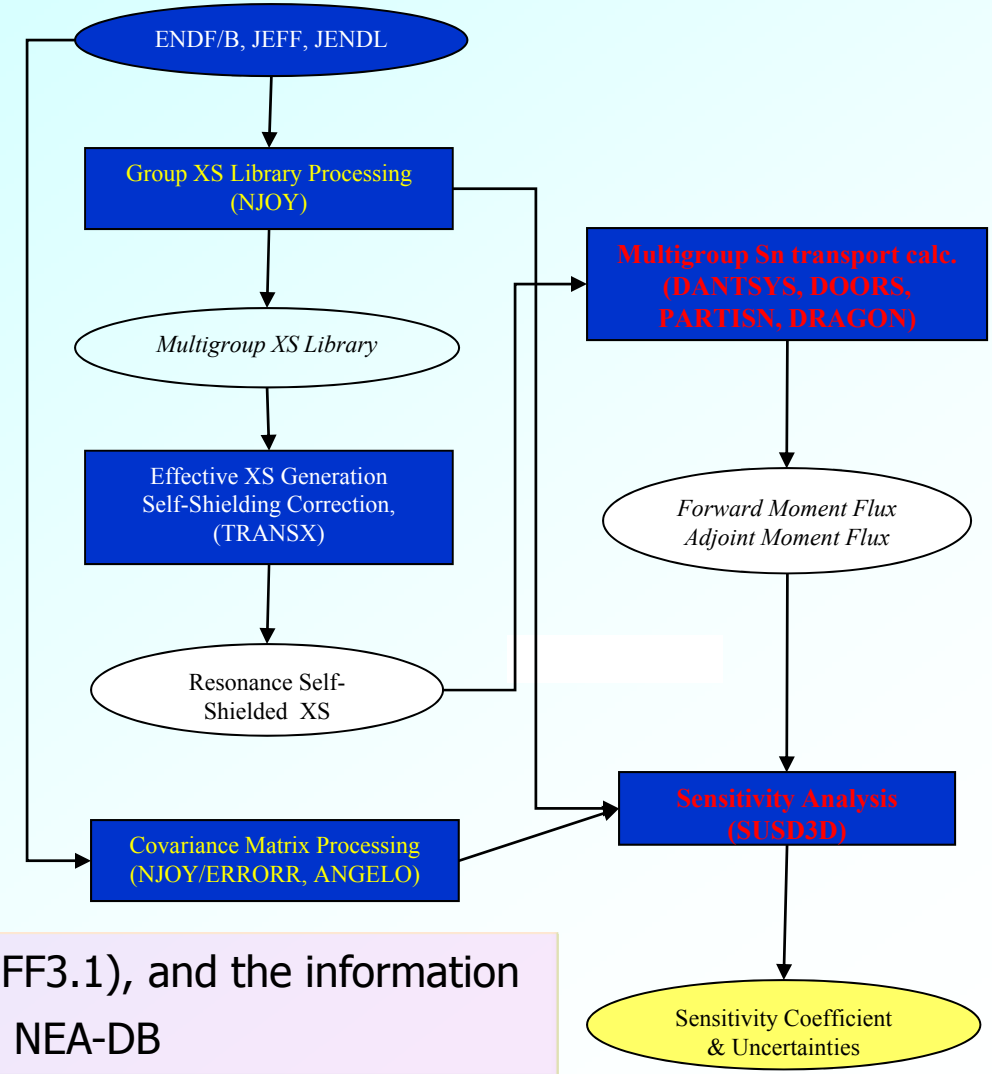
# Scope of presentation

- *Computational methods used for SU analysis*
- *ZPR6-7 fast critical benchmarks*
- *ZPR-9 benchmarks*

# Computational Methods and Procedures

- DANTSYS
  - -SN transport code (1D, 2D, 3D)
- TRANSX
  - - Processes MATXS format library for SN transport code
  - - Self-shielding factor method
- SUSD3D
  - - Multi-dimensional, SN based XS sensitivity and uncertainty
  - - First-order perturbation theory




- All computer codes, XS library (KAFAX, JEFF3.1), and the information on benchmarks publicly available through NEA-DB

# Multigroup Cross-section Libraries

- **NEA-1650 ZZ-KAFAX-F22**, 80 and 24 Groups Cross-Section Library in MATXS Format Based on JEF-2.2 for Fast Reactors
- **NEA-1815: ZZ KAFAX-E70**, 150 n/12 g Group Cross Section Library in MATXS Format based on ENDF/B-VII.0 for Fast Reactors (U-238 data deficient)
- **NEA-1816: ZZ KAFAX-F31**, 150 n/12 g Group Cross Section Library in MATXS Format based on JEFF-3.1 for Fast Reactors (U-238 data deficient)
- **NEA-1817: ZZ KAFAX-J33**, 150 n/12 g Group Cross Section Library in MATXS Format based on JENDL-3.3 for Fast Reactors (U-238 data deficient)
- **NEA-1847: ZZ-MATJEFF31.BOLIB**, JEFF-3.1 Multigr Coupled(199n + 42gamma) X-Section Lib.in MATXS Fmt for Nuclear Fission Applications
- **NEA-1801: ZZ VITJEFF31.BOLIB**, JEFF-3.1 Multigr Coupled (199n + 42gamma) X-Section Lib. in AMPX Fmt for Nuclear Fission Applications

# Processing Codes and Multigroup Covariance Data Libraries

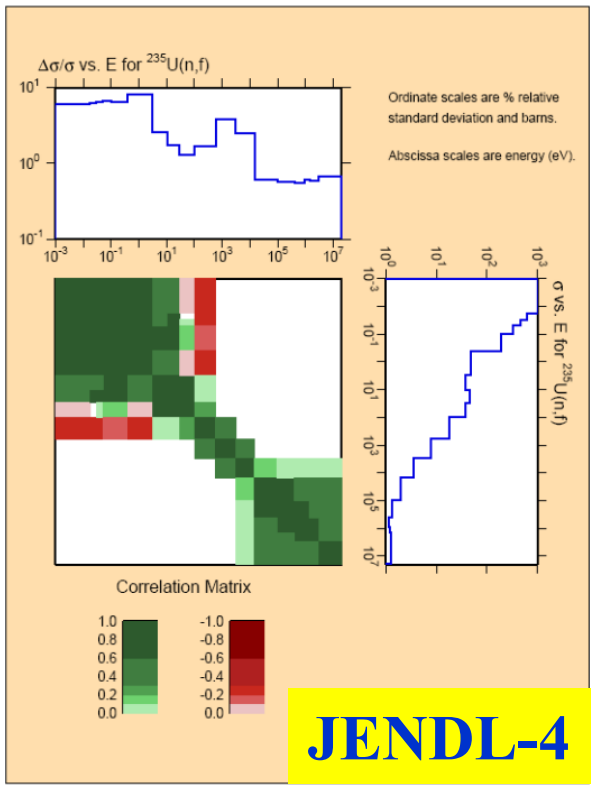
- **NJOY/ERRORR**: processing for covariance matrices **JENDL-3.3 and JENDL-4.0** (MF=31-35)
- **ANGELO-LAMBDA** codes and the libraries **ZZ-SCALE5.1/COVA-44G** and **ZZ-SCALE6/COVA-44G**: utility programs for interpolation and mathematical verification of the matrices was extended to handle the 44-group covariances available in SCALE-5.1. Work carried out within the Expert Group on Uncertainty Analysis in Modelling (UAM).

H-1, H-ZrH, H-poly, H-freegas, H-2, H2-freegas, H-3, He-3, He-4, Li-6, Li-7, Be-7, Be-9, Be-bound, B-10, B-11, C-0, C-graphite, N-14, N-15, O-16, O-17, F-19, Na-23, Mg-0, Mg-24, Mg-25, Mg-26, Al-27, Si-0, Si-28, Si-29, Si-30, P-31, S-0, S-32, S-34, S-36, Cl-0, Cl-35, Cl-37, Ar-36, Ar-38, Ar-40, K-0, K-39, K-40, K-41, Ca-0, Ca-40, Ca-42, Ca-43, Ca-44, Ca-46, Ca-48, Sc-45, Ti-0, Ti-46, Ti-47, Ti-48, Ti-49, Ti-50, V-0, Cr-50, Cr-52, Cr-53, Cr-54, Mn-55, Fe-0, Fe-54, Fe-56, Fe-57, Fe-58, Co-58, Co-58(m), Co-59, Ni-58, Ni-59, Ni-60, Ni-61, Ni-62, Ni-64, Cu-63, Cu-65, Ga-0, Ga-69, Ga-71, Ge-70, Ge-72, Ge-73, Ge-74, Ge-76, As-74, As-75, Se-74, Se-76, Se-77, Se-78, Se-79. Se-80, Se-82, Br-79, Br-81, Kr-78, Kr-80, Kr-82, Kr-83, Kr-84, Kr-85, Kr-86, Rb-85, Rb-86, Rb-87, Sr-84, Sr-86, Sr-87, Sr-88, Sr-89, Sr-90, Y-89, Y-89, Y-90, Y-91, Zr-0, Zr-90, Zr-91, Zr-92, Zr-93, Zr-94, Zr-95, Zr-96, Nb-93, Nb-94, Nb-95, Mo-0, Mo-92, Mo-94, Mo-95, Mo-96, Mo-97, Mo-98, Mo-99, Mo-100, Tc-99, Ru-96, Ru-98, Ru-99, Ru-100, Ru-101, Ru-102, Ru-103, Ru-104, Ru-105, Ru-106, Rh-103, Rh-105, Pd-102, Pd-104, Pd-105, Pd-106, Pd-107, Pd-108, Pd-110, Ag-107, Ag-109, Ag-111, Cd-0, Cd-106, Cd-108, Cd-110, Cd-111, Cd-112, Cd-113, Cd-114, Cd-115(m), Cd-116, In-0, In-113, In-115, Sn-112, Sn-113, Sn-114, Sn-115, Sn-116, Sn-117, Sn-118, Sn-119, Sn-120, Sn-122, Sn-123, Sn-124, Sn-125, Sb-121, Sb-123, Sb-124, Sb-125, Sb-126, Te-120, Te-122, Te-123, Te-124, Te-125, Te-126, Te-127(m), Te-128, Te-129(m), Te-130, I-127, I-129, I-130, I-131, I-135, Xe-123, Xe-124, Xe-126, Xe-128, Xe-129, Xe-130, Xe-131, Xe-132, Xe-133, Xe-134, Xe-135, Xe-136, Cs-133, Cs-134, Cs-135, Cs-136, Cs-137, Ba-130, Ba-132, Ba-133, Ba-135, Ba-136, Ba-137, Ba-138, Ba-140, La-138, La-139, La-140, Ce-136, Ce-138, Ce-139, Ce-140, Ce-141, Ce-142, Ce-143, Ce-144, Pr-141, Pr-142, Pr-143, Nd-142, Nd-143, Nd-144, Nd-145, Nd-146, Nd-147, Nd-148, Nd-150, Pm-147, Pm-148, Pm-148(m), Pm-149, Pm-151, Sm-144, Sm-147, Sm-148, Sm-149, Sm-150, Sm-151, Sm-152, Sm-153, Sm-154, Eu-151, Eu-152, Eu-153, Eu-154, Eu-155, Eu-156, Eu-157, Gd-152, Gd-153, Gd-154, Gd-155, Gd-156, Gd-157, Gd-158, Gd-160, Tb-159, Tb-160, Dy-156, Dy-158, Dy-160, Dy-161, Dy-162, Dy-163, Dy-164, Ho-165, Er-162, Er-164, Er-166, Er-167, Er-168, Er-170, Lu-175, Lu-176, Hf-0, Hf-174, Hf-176, Hf-177, Hf-178, Hf-179, Hf-180, Ta-181, Ta-182, W-0, W-182, W-183, W-184, W-186, Re-185, Re-187, Ir-191, Ir-193, Au-197, Hg-196, Hg-198, Hg-199, Hg-200, Hg-201, Hg-202, Hg-204, Pb-204, Pb-206, Pb-207, Pb-208, Bi-209, Ac-225, Ac-226, Ac-227, Th-227, Th-228, Th-229, Th-230, Th-232, Th-233, Th-234, Pa-231, Pa-232, Pa-233, U-232, U-233, U-234, U-235, U-235, U-236, U-237, U-238, U-239, U-240, U-241, Np-235, Np-236, Np-237, Np-238, Pu-236, Pu-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-243, Pu-244, Pu-246, Am-241, Am-242, Am-242(m), Am-243, Am-244, Cm-241, Cm-242, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Cm-248, Cm-249, Cm-250, Bk-249, Bk-250, Cf-249, Cf-250, Cf-251, Cf-252, Cf-253, Cf-254, Es-253, Es-254, Es-255, Fm-255

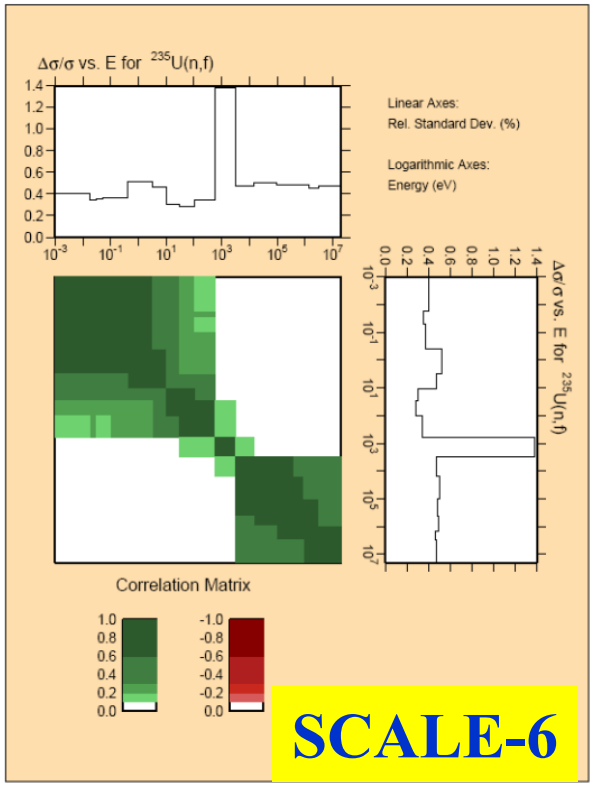
# ZZ-SCALE6/COVA-44G, 44-group cross section covariance matrix library extracted from SCALE6

- Among the materials in the SCALE library with covariances taken from high-fidelity nuclear data evaluations are the following:
  (a) ENDF/B-VII evaluations *(includes both VII.0 and pre-release covariances proposed for VII.1):* Au, $^{209}$Bi, $^{59}$Co, $^{152,154,155,156}$Gd, $^{191,193}$I, $^{7}$Li, $^{23}$Na, $^{93}$Nb, $^{58}$Ni, $^{99}$Tc, $^{232}$Th, $^{48}$Ti, $^{239}$Pu, $^{233,235,238}$U, V
  (b) ENDF/B-VI evaluations: Al, $^{241}$Am, $^{10}$B, $^{12}$C, $^{50,52,53,54}$Cr, $^{63,65}$Cu, $^{54,56,57}$Fe, In, $^{55}$Mn, $^{60,61,62,64}$Ni, $^{206,207,208}$Pb, $^{242}$Pu, $^{28,29}$Si
  (c) JENDL-3.3 evaluations: $^{11}$B, $^{1}$H, $^{16}$O, $^{240,241}$Pu
- At the other end of the spectrum from high fidelity data, "low-fidelity" (lo-fi) covariances (BLO data) are defined to be those that are estimated independently of a specific data evaluation. The approximate covariance data in SCALE are based on results from a collaborative project funded by the Department of Energy Nuclear Criticality Safety Program to generate lo-fi covariances over the energy range from $10^{-5}$ eV to 20 MeV for materials without covariances in ENDF/B-VII.0. Nuclear data experts at BNL, LANL, and ORNL devised simple procedures to estimate data uncertainties in the absence of high fidelity covariance evaluations. The result of this project is a set of covariance data in ENDF/B file 33 format that can be processed into multigroup covariances.

# U-235(n,f)

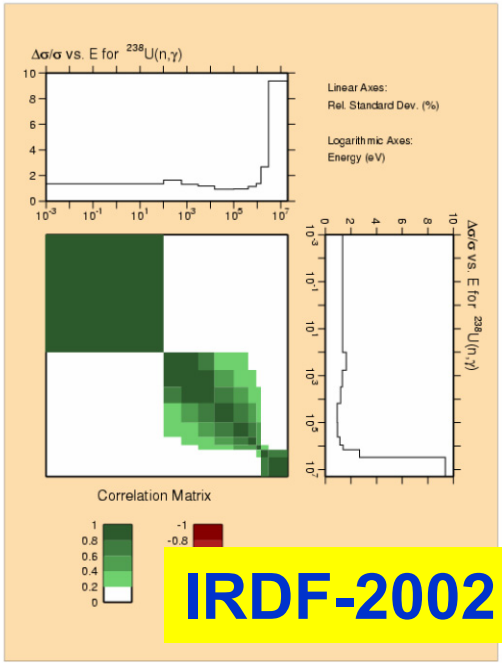



**JENDL-4**

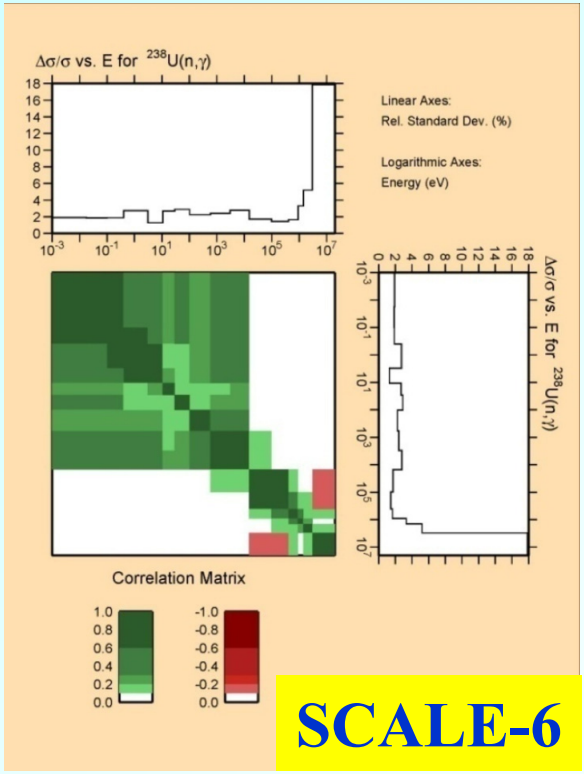



**SCALE-6**

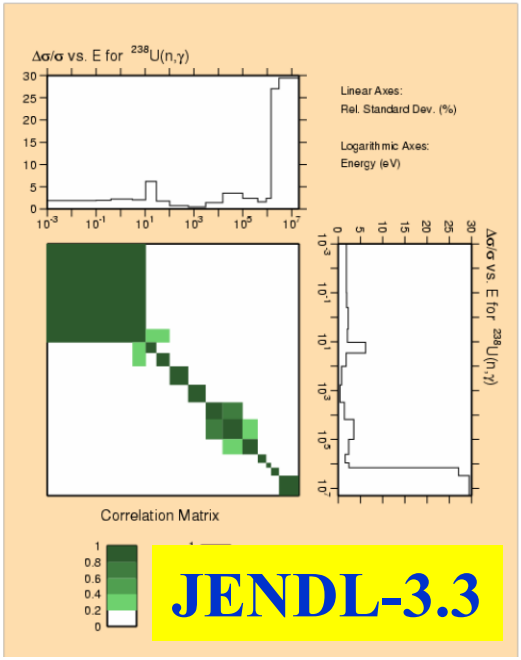
# U-238(n,γ)



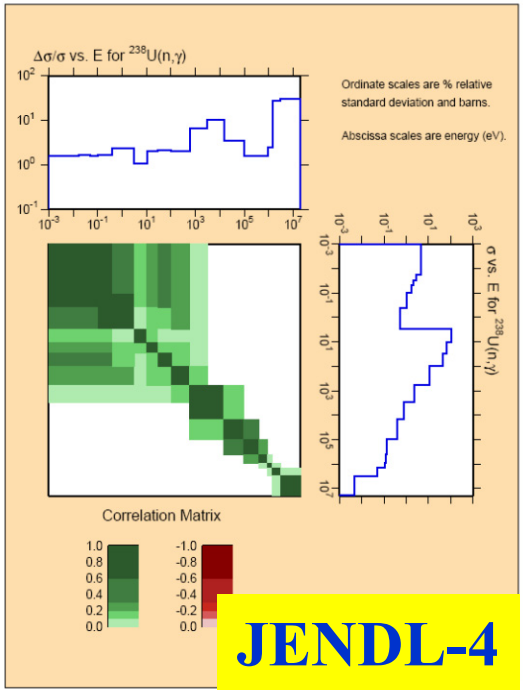

IRDF-2002




SCALE-6

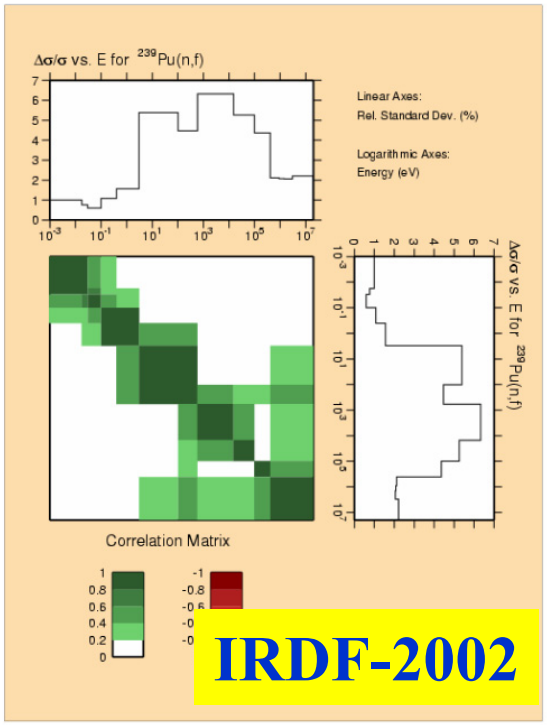



JENDL-3.3




JENDL-4

# Pu-239(n,f)

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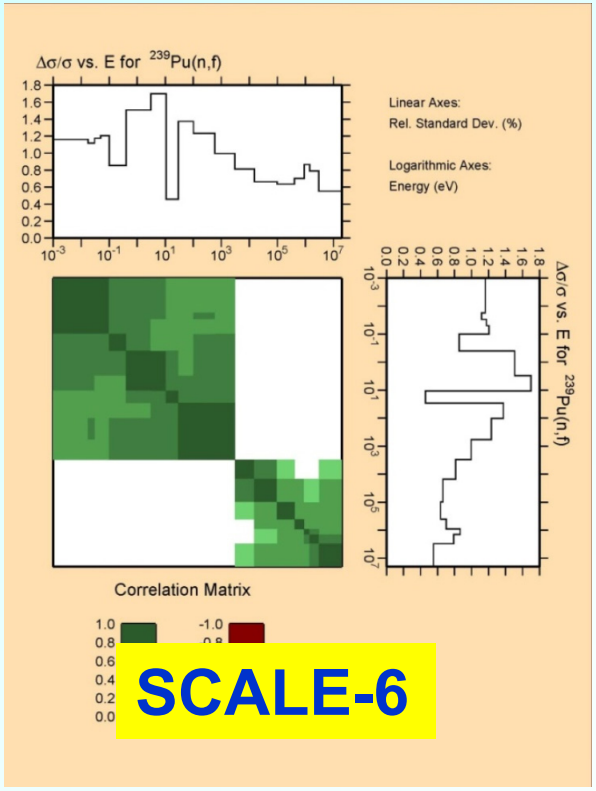
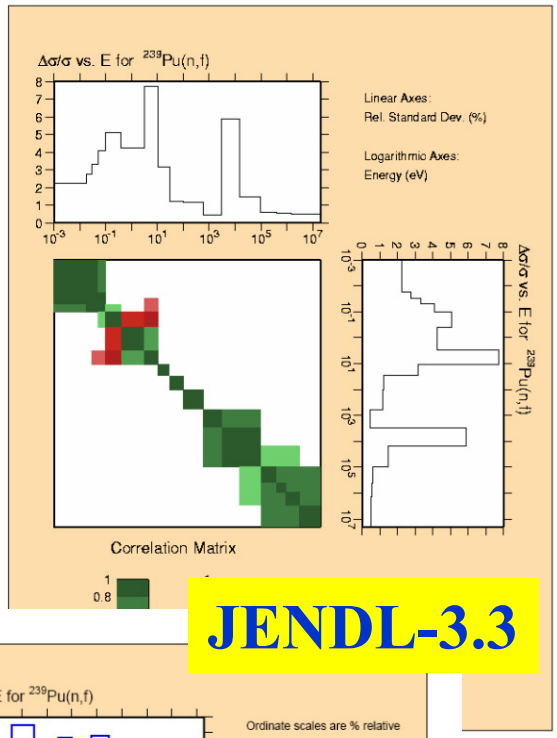
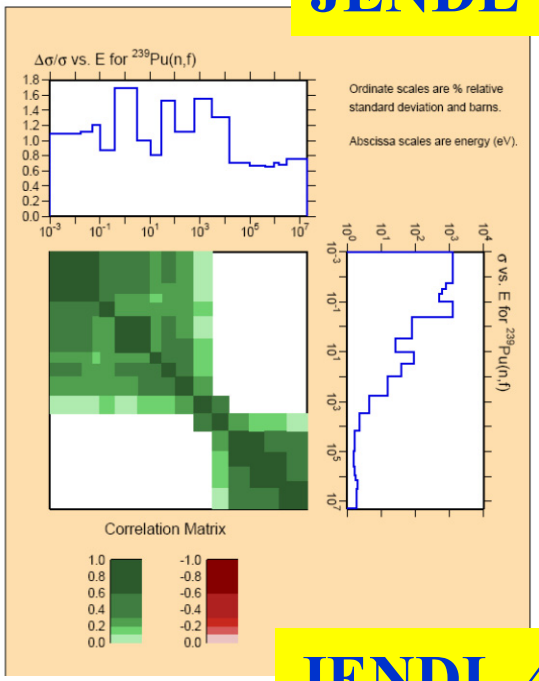



SCALE-6




JENDL-3.3




JENDL-4

# ZPR 6-7

**TWODANT 2D R-Z**

**NEA-1650 ZZ-KAFAX-F22** (80 n groups JEFF 2.2)
$k_{eff}$=0.985169 ($P_1S_4$)

**NEA-1815: ZZ-KAFAX-E70** 150 n groups ENDF/B-VII.0 ($^{238}U$ data recalculated)
$k_{eff}$=1.0009163 ($P_1S_4$, direct)  $k_{eff}$=1.0009171 ($P_1S_4$, adjoint)
$k_{eff}$=1.0006591 ($P_3S_4$, direct)

(with uncorrected $^{238}U$ $k_{eff}$~1.08)

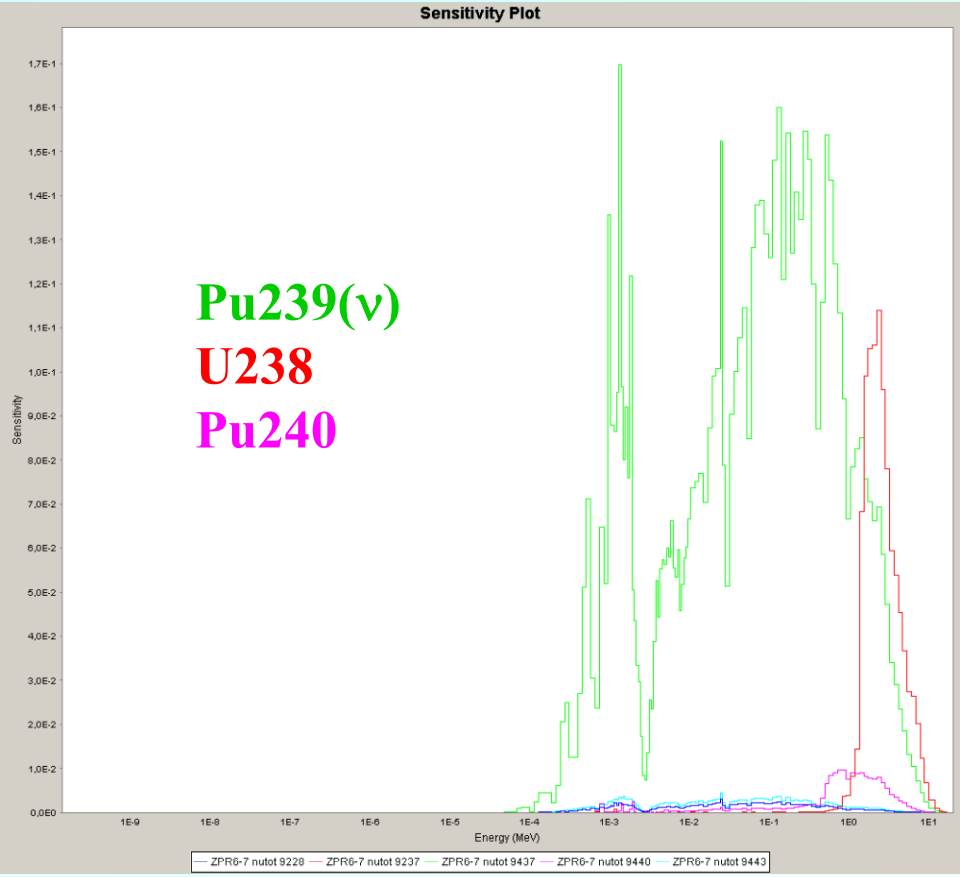
# ZPR 6-7

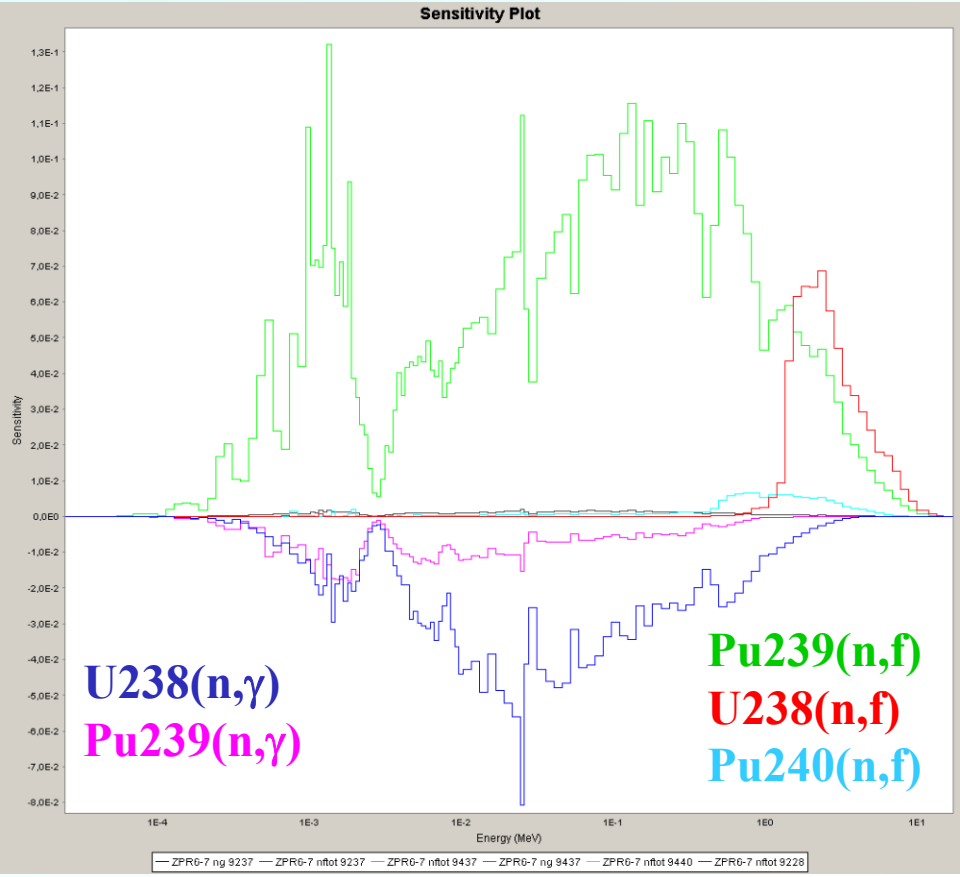
| | Sensitivity (%) | | Δ (%) |
|---|---|---|---|
| | Σ | Σ (abs) | |
| $^{12}$C | $-8.10 \cdot 10^{-5}$ | $8.10 \cdot 10^{-5}$ | $5.5 \cdot 10^{-5}$ |
| $^{16}$O | $-1.75 \cdot 10^{-2}$ | $1.75 \cdot 10^{-2}$ | 0.023 |
| $^{23}$Na | $-1.53 \cdot 10^{-2}$ | $1.53 \cdot 10^{-2}$ | 0.086 |
| Cr | $-3.37 \cdot 10^{-3}$ | $1.00 \cdot 10^{-2}$ | 0.028 |
| $^{55}$Mn | $-7.21 \cdot 10^{-4}$ | $2.95 \cdot 10^{-3}$ | 0.012 |
| Fe | $-2.05 \cdot 10^{-2}$ | $4.57 \cdot 10^{-2}$ | 0.118 |
| Ni | $-4.49 \cdot 10^{-3}$ | $1.17 \cdot 10^{-2}$ | 0.028 |

| | Sensitivity (%/%) | | Δ (%) |
|---|---|---|---|
| | Σ | Σ (abs) | |
| $^{235}$U | $2.03 \cdot 10^{-2}$ | $2.27 \cdot 10^{-2}$ | 0.026 |
| $^{238}$U | $-9.45 \cdot 10^{-3}$ | $5.00 \cdot 10^{-1}$ | 0.758 |
| $^{239}$Pu | 1.357 | 1.49 | 0.620 |
| $^{240}$Pu | $7.12 \cdot 10^{-3}$ | $3.78 \cdot 10^{-2}$ | 0.068 |
| $^{241}$Pu | $3.27 \cdot 10^{-2}$ | $3.47 \cdot 10^{-2}$ | 0.018 |
| $^{241}$Am | $1.23 \cdot 10^{-5}$ | $1.43 \cdot 10^{-3}$ | 0.003 |

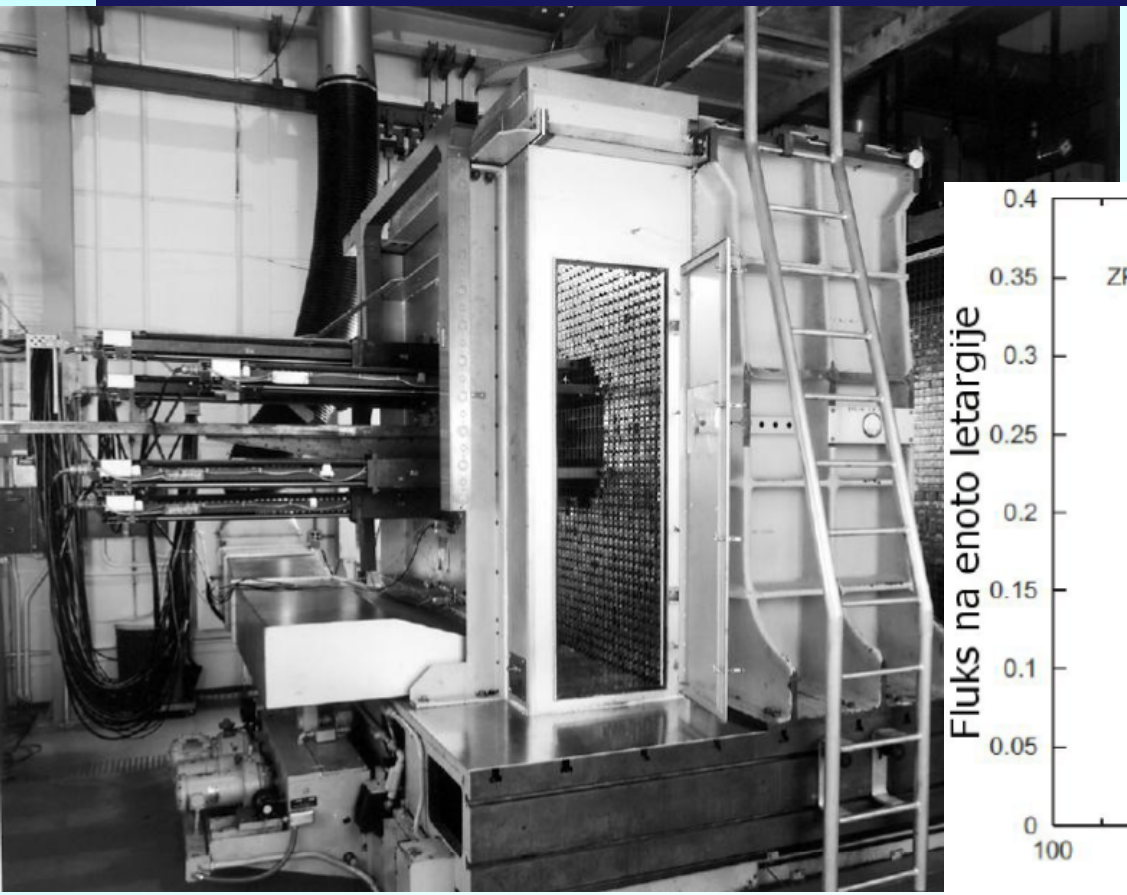
Total uncertanty = 0.99 %

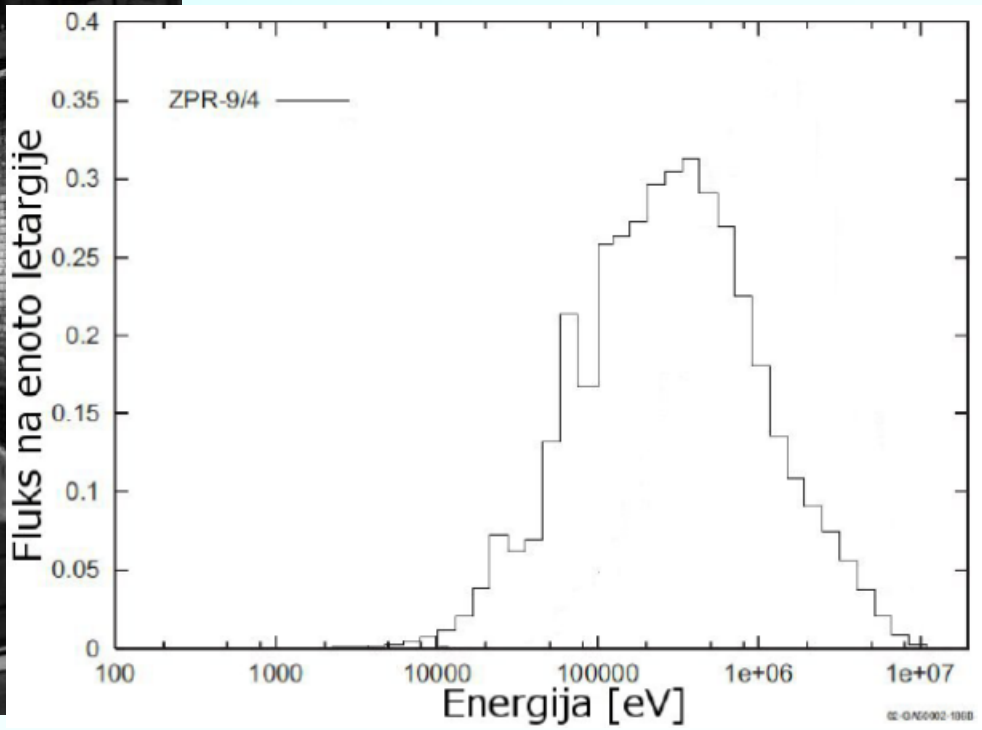
# ZPR 6-7


Sensitivity Plot
Pu239(ν)
U238
Pu240
Sensitivity
Energy (MeV)
ZPR6-7 nutot 9228
ZPR6-7 nutot 9237
ZPR6-7 nutot 9437
ZPR6-7 nutot 9440
ZPR6-7 nutot 9443


Sensitivity Plot
U238(n,γ)
Pu239(n,γ)
Pu239(n,f)
U238(n,f)
Pu240(n,f)
Sensitivity
Energy (MeV)
ZPR6-7 ng 9237
ZPR6-7 nftot 9237
ZPR6-7 nftot 9437
ZPR6-7 ng 9437
ZPR6-7 nftot 9440
ZPR6-7 nftot 9228

# ZPR-9 Reactor

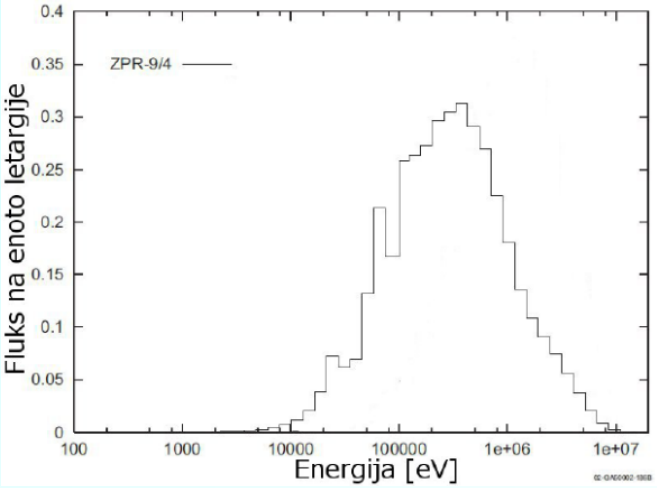


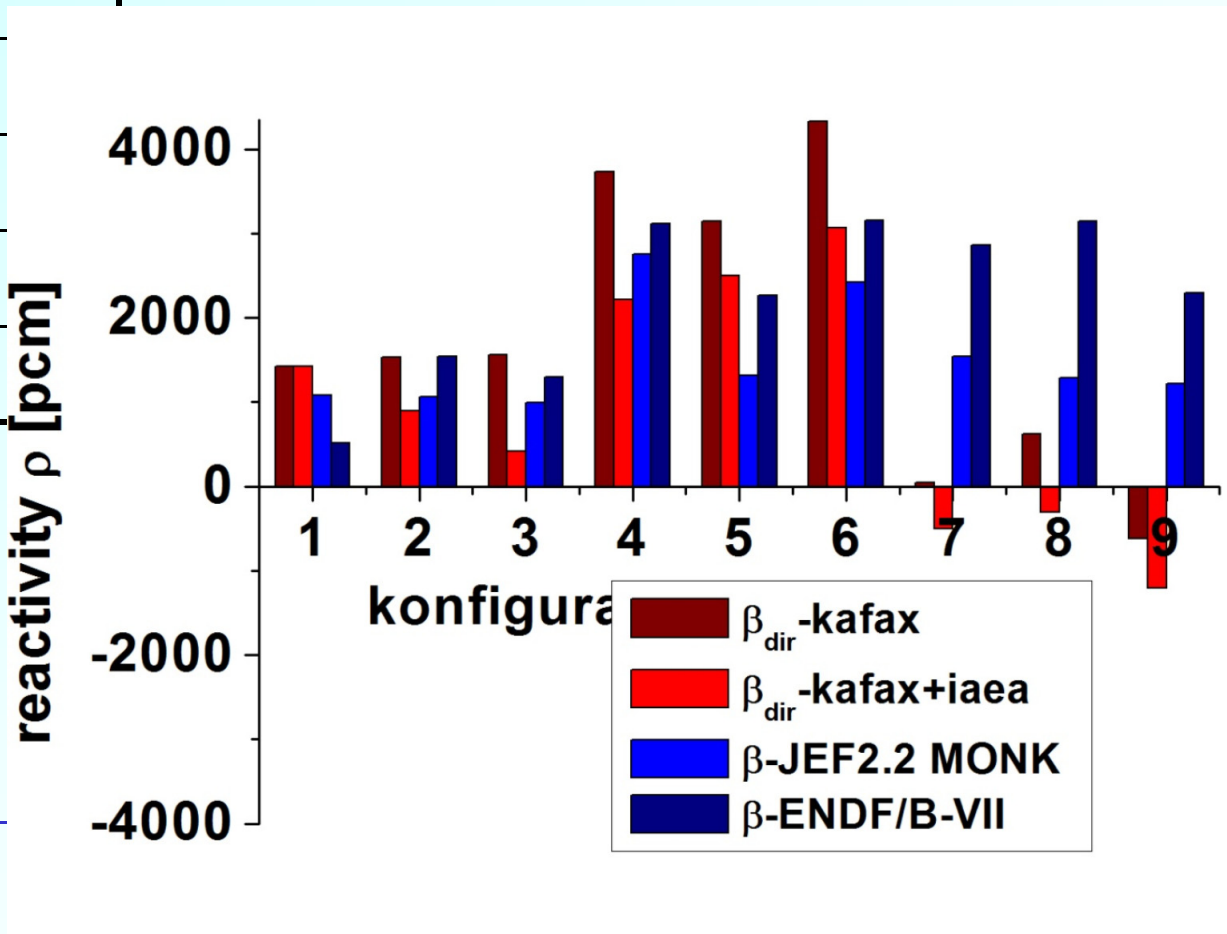



Diploma work of J. Senegacnik

| ZPR-1 | no W |
|---|---|
| 2 | 25% $^{238}U \rightarrow W$ |
| 3 | 50% $^{238}U \rightarrow W$ |
| 4 | 100% $^{238}U \rightarrow W$ |
| 5 | C |
| 6 | Al |
| 7 | Reflector |
| 8 | Reflector |
| 9 | reflector |

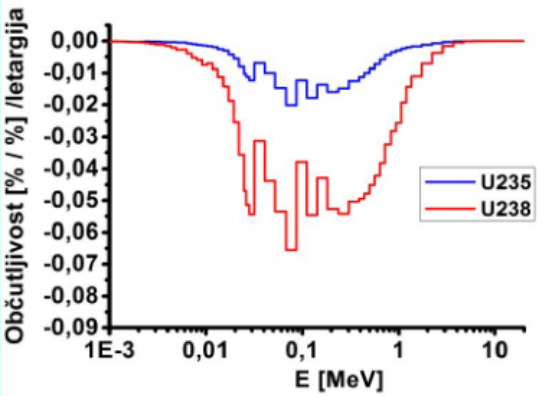
# ZPR-9



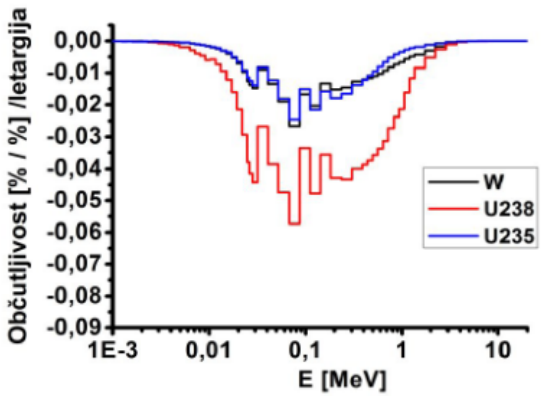



## ZPR-9 benchmarks

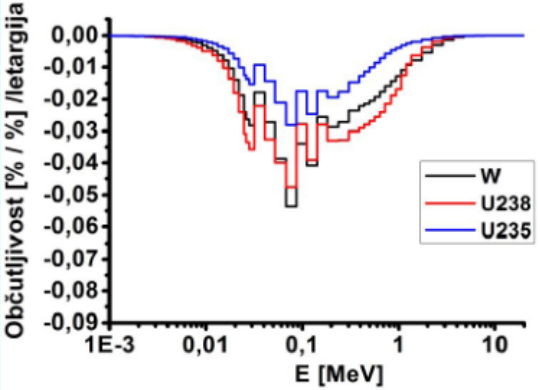
Sensitivity of k-eff to neutron capture on uranium ($^{235}U$, $^{238}U$) and tungsten.



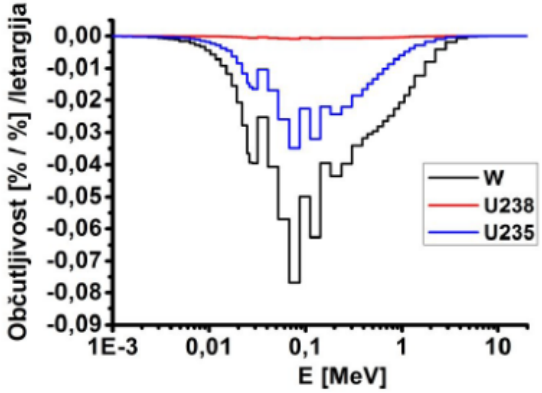

(a) konfiguracija 1



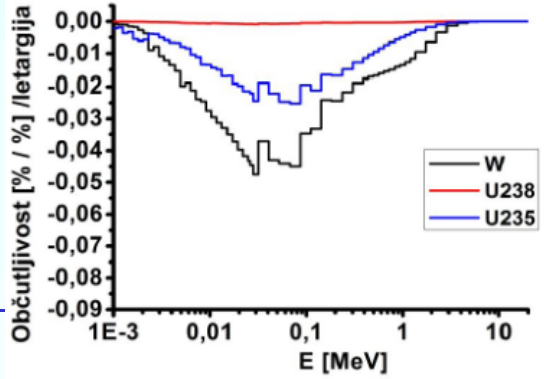

(b) konfiguracija 2



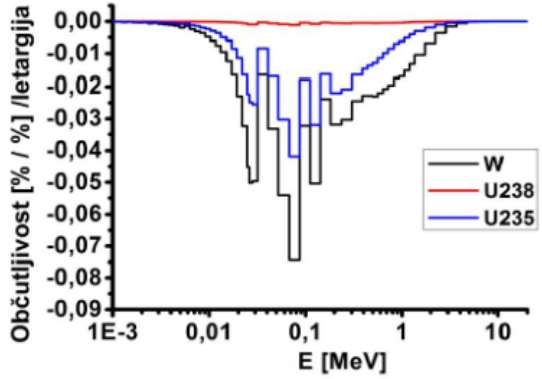

(c) konfiguracija 3




(d) konfiguracija 4




(e) konfiguracija 5




(f) konfiguracija 6

# Integral sensitivity to neutron capture

| k. | $^{182}$W | $^{183}$W | $^{184}$W | $^{186}$W | *naravni* W | $^{235}$U | $^{238}$U |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | -50,5 | -203,5 |
| 2 | -18,2 | -14,9 | -17,3 | -11,7 | -62,1 | -58,2 | -168,7 |
| 3 | -35,1 | -28,8 | -33,4 | -22,7 | -119,9 | -64,4 | -134,3 |
| 4 | -55,0 | -44,2 | -51,1 | -34,6 | -184,9 | -80,7 | -2,6 |
| 5 | -49,8 | -48,4 | -47,4 | -33,2 | -178,8 | -99,4 | -3,6 |
| 6 | -45,8 | -37,6 | -43,4 | -29,5 | -156,4 | -83,3 | -2,7 |
| 7 | -45,6 | -42,1 | -42,5 | -29,0 | -159,3 | -96,4 | -3,3 |
| 8 | -46,7 | -41,5 | -40,6 | -31,0 | -159,7 | -93,7 | -3,1 |
| 9 | -46,5 | -43,6 | -42,6 | -30,2 | -162,9 | -98,4 | -3,4 |

# Uncertainty in k-eff (%)

| **SCALE6** | **Uncertainty (%)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **ZPR1** | **ZPR2** | **ZPR3** | **ZPR4** | **ZPR5** | **ZPR6** | **ZPR7** | **ZPR8** | **ZPR9** |
| $^{235}$U (n,f) | 0.22 | 0.23 | 0.24 | 0.25 | 0.24 | 0.25 | 0.23 | 0.23 | 0.23 |
| **$^{235}$U (n,$\gamma$)** | **1.33** | **1.55** | **1.72** | **2.13** | **2.73** | **2.24** | **2.24** | **2.25** | **2.25** |
| $^{235}$U ($\nu$) | 0.12 | 0.16 | 0.14 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| **$^{238}$U (inel.)** | **1.70** | **0.91** | **0.48** | / | / | / | / | / | / |
| Fis.sp. | 0.41 | 0.37 | 0.30 | 0.11 | 0.08 | 0.09 | 0.05 | 0.07 | 0.05 |
| **W** | / | **0.51** | **1.01** | **1.40** | **1.48** | **1.20** | **1.27** | **1.26** | **1.23** |
| **Total** | 2.2 | 1.9 | 2.1 | 2.6 | 3.2 | 2.6 | 2.6 | 2.6 | 2.6 |

# Uncertainty in k-eff (%)

| JENDL-4 & IAEA | Uncertainty (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **ZPR1** | **ZPR2** | **ZPR3** | **ZPR4** | **ZPR5** | **ZPR6** | **ZPR7** | **ZPR8** | **ZPR9** |
| $^{235}$U (n,f) | 0.25 | 0.27 | 0.29 | 0.30 | 0.34 | 0.30 | 0.31 | 0.30 | 0.31 |
| $^{235}$U (n,$\gamma$) | 0.12 | 0.14 | 0.15 | 0.20 | 0.22 | 0.20 | 0.20 | 0.20 | 0.21 |
| $^{235}$U ($\nu$) | 0.18 | 0.20 | 0.21 | 0.24 | 0.21 | 0.23 | 0.20 | 0.21 | 0.20 |
| **$^{235}$U JENDL4** | 0.37 | 0.39 | 0.41 | 0.43 | 0.45 | 0.43 | 0.42 | 0.41 | 0.43 |
| $^{238}$U (inel.) | 0.97 | 0.53 | 0.29 | / | / | / | / | / | / |
| **$^{238}$U JENDL4** | 1.09 | 0.67 | 0.45 | / | / | / | / | / | / |
| **Fis.sp.** | 0.56 | 0.46 | 0.38 | 0.12 | 0.08 | 0.09 | 0.05 | 0.06 | 0.04 |
| **W IAEA** | / | 0.14 | 0.28 | 0.43 | 0.36 | 0.36 | 0.32 | 0.32 | 0.31 |
| **Total** | 1.3 | 0.9 | 0.8 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |

# CONCLUSIONS

- **ZPR 6-7 and ZPR 9 benchmarks analysed using SUSD3D-DANTSYS calculational cross-section sensitivity-uncertainty scheme. Covariance matrices of different origin (e.g. SCALE-6 & ANGELO2, JENDL-4).**
- **ZPR-9: high C/E discrepancies can be explained either by deficiencies in W or in U-235 & U-238 nuclear data (provided measurement uncertainties are realistic).**
- **Difficulties encountered:**
  - **Support needed for the GENDR project updates**
  - **Multigroup transport XS libraries reliable**
  - **Covariance matrices – large differences betweed the data will result in very different adjustments**