IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Preliminary Results from IRSN

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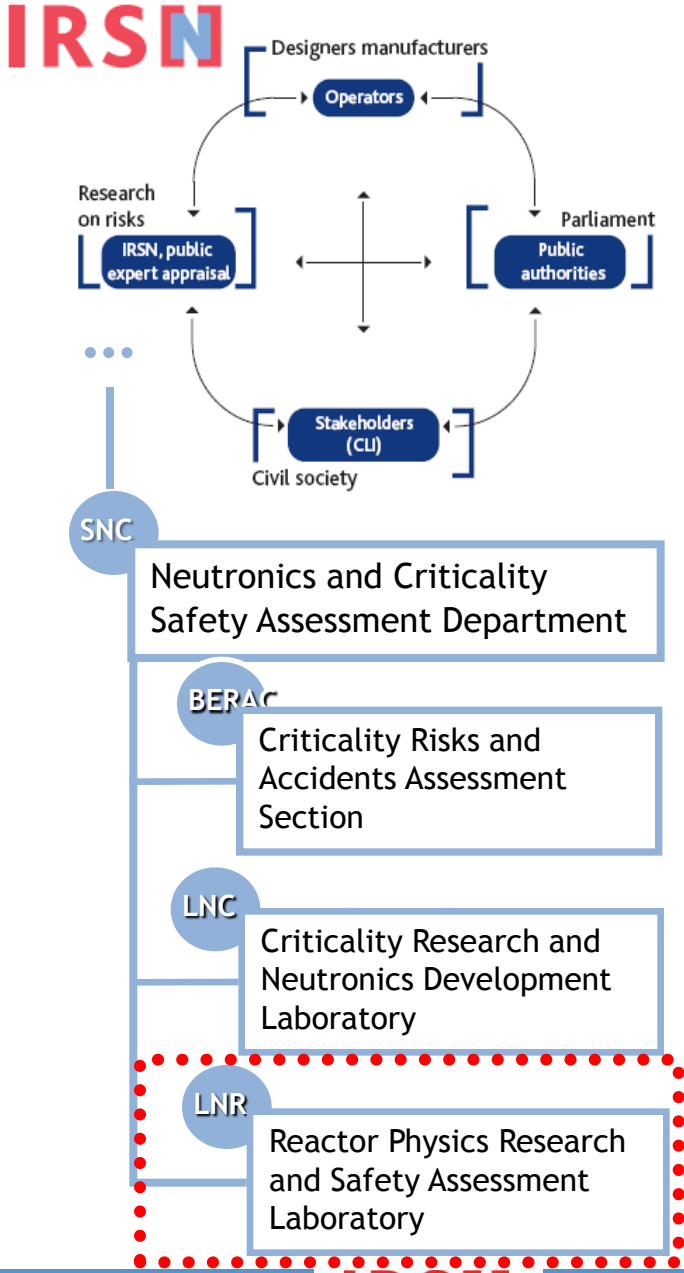
WPEC Sg. 33 Meeting
Issy-les-Moulineaux
May 22-23, 2012

Our Motivation

is not to adjust nuclear data, but to establish the high-confidence k_{eff} bias and the bias uncertainty for ***validation of neutronics simulations for safety assessment***

- Application systems
  - Fuel cycle, research reactors, current reactors, advanced reactor concepts
- Application parameters
  - Critical mass, design parameters
- Objective
  - Justify safety margins provided by designers/manufactures for the application systems



Computations for this Exercise

- *SCALE6.1*

  Nuclear data: 238-group ENDF-B/VI.8 and ENDF-B/VII

  Neutron transport: KENOVa

  Sensitivities: TSUNAMI-1D (Deterministic code; GPT and 1st order PT) and TSUNAMI-3D (MC code; 1st order PT)

- ERANOS 2.2

  Nuclear data: 33-group ENDF-B/VI.8

  Neutron transport &

  Sensitivities: BISTRO+ (Transport solver, RZ geometry)

Computations (cont'd)

#	Configuration	Parameter	Parameter calculated with	Sensitivity calculated with
1	JEZEBEL	KEFF	**KENOVa**	**TSUNAMI-ID,** -3D
2	JEZEBEL	F28/F25	**KENOVa**	**TSUNAMI-ID,** -3D
3	JEZEBEL	F49/F25	**KENOVa**	**TSUNAMI-ID,** -3D
4	JEZEBEL	F37/F25	**KENOVa**	**TSUNAMI-ID,** -3D
5	JEZEBEL Pu240	KEFF	**KENOVa**	**TSUNAMI-ID,** -3D
6	FLATTOP-PU	KEFF	**KENOVa**	**TSUNAMI-3D**
7	FLATTOP-PU	F28/F25	KENOVa	TSUNAMI-3D
8	FLATTOP-PU	F37/F25	**KENOVa**	**TSUNAMI-3D**
9	ZPR6-7	KEFF	**KENOVa** & ERANOS	**TSUNAMI-3D** & ERANOS
10	ZPR6-7	F28/F25	-	-
11	ZPR6-7	F49/F25	-	-
12	ZPR6-7	C28/F25	-	-
13	ZPR6-7 Pu240	KEFF	**KENOVa** & ERANOS	**TSUNAMI-3D** & ERANOS
14	ZPPR-9	KEFF	**KENOVa** & ERANOS	**TSUNAMI-3D** & ERANOS
15	ZPPR-9	F28/F25	-	-
16	ZPPR-9	F49/F25	-	-
17	ZPPR-9	C28/F25	-	-
18	ZPPR-9	NA VOID STEP3	-	-
19	ZPPR-9	NA VOID STEP5	-	-
20	JOYO MK-I	KEFF	**KENOVa** & ERANOS	**TSUNAMI-3D** & ERANOS

Calculations used in adjustment are shown in red

Code/Data for Adjustment

BERING code (IRSN) by E. Ivanov

- Adjustment was applied to k_{eff} values only
- Data used for this exercise
  - Sensitivities: from TSUNAMI-1D and -3D
  - Energy structures: 44 and 238 groups
  - Experimental correlations: by Makoto Ishikawa
  - ND Covariances: COMMARA-2.0 for Sg.33
  - Simplified models for benchmarks
  - Correction factors: by INL

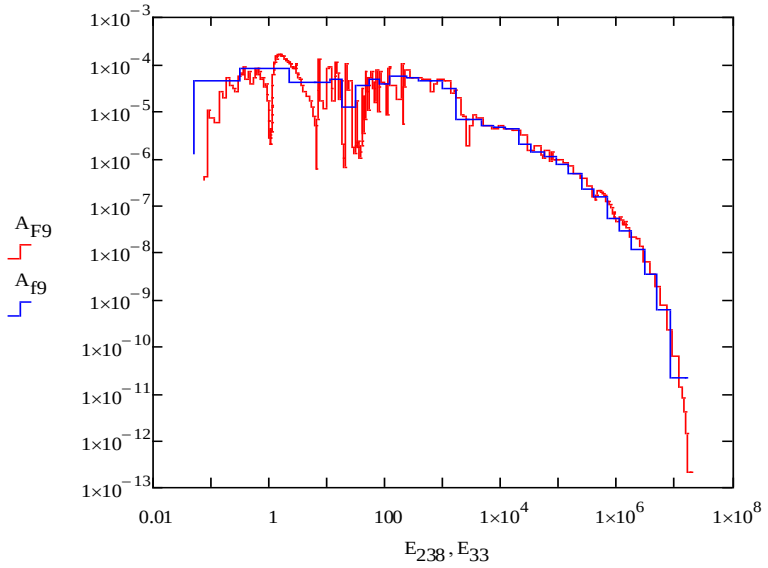
  } from Sg. 33 web-site
- Other data can be used
  - Sensitivities: from ERANOS
  - Energy structures: 33 groups
  - Experimental correlations: any
  - ND Covariances: JENDL4.0, TENDL…

Data for Adjustment: k_{eff} Sensitivities

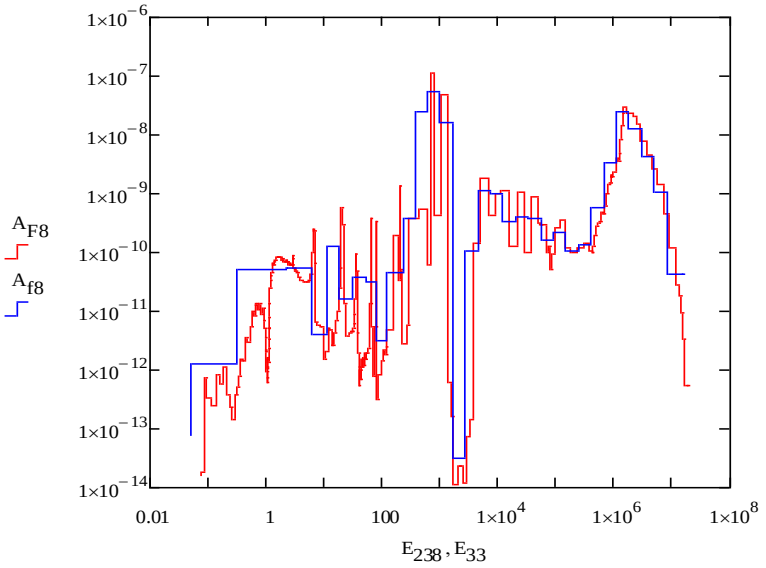
Verification of data transfer from 238 groups to 33 groups

$S_k(E_g)/\Delta E_g$

^{238}U fission for ABR



^{239}Pu fission for ABR

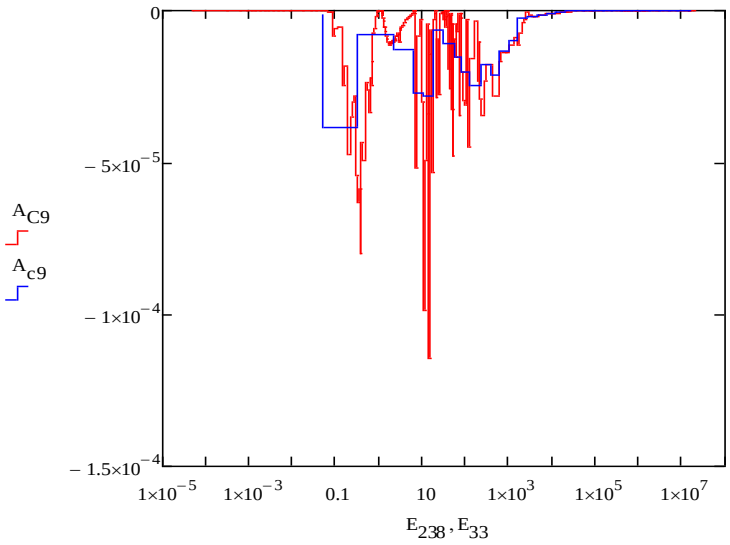


Data for Adjustment: k_{eff} Sensitivities

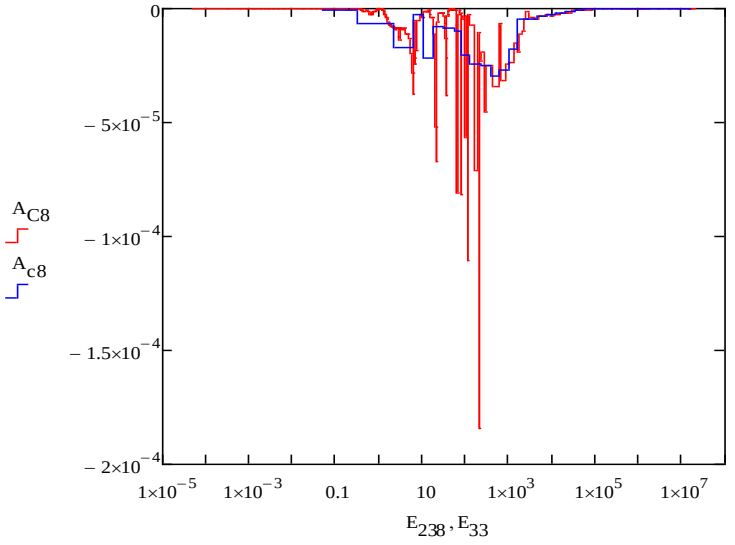
Verification of data transfer from 238 groups to 33 groups

$S_k(E_g)/\Delta E_g$

^{238}U capture for ABR



^{239}Pu capture for ABR

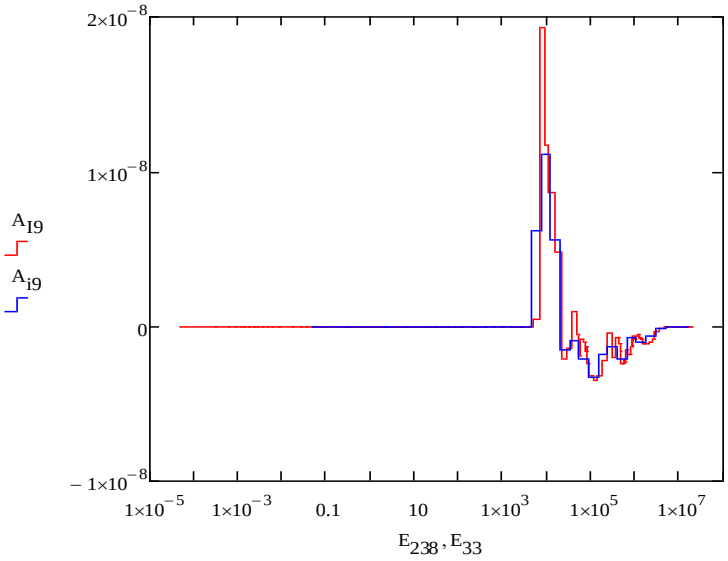


Data for Adjustment: k_{eff} Sensitivities

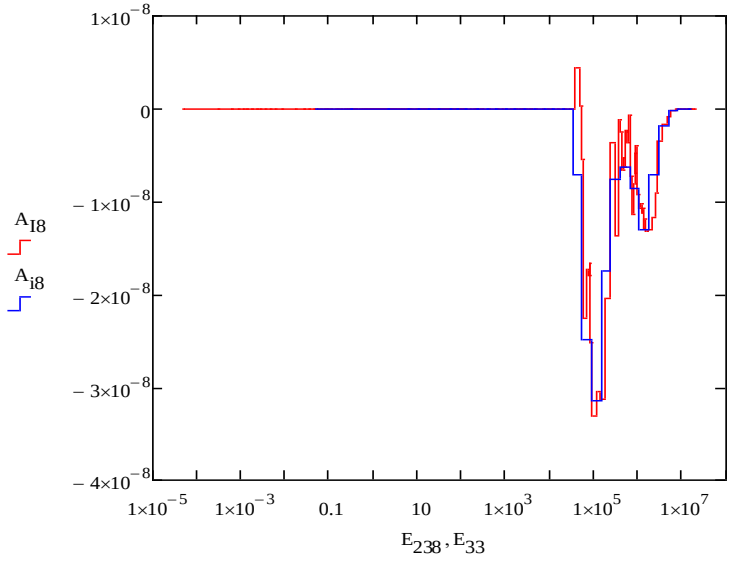
Verification of data transfer from 238 groups to 33 groups

$S_k(E_g)/\Delta E_g$

^{238}U inelastic for ABR



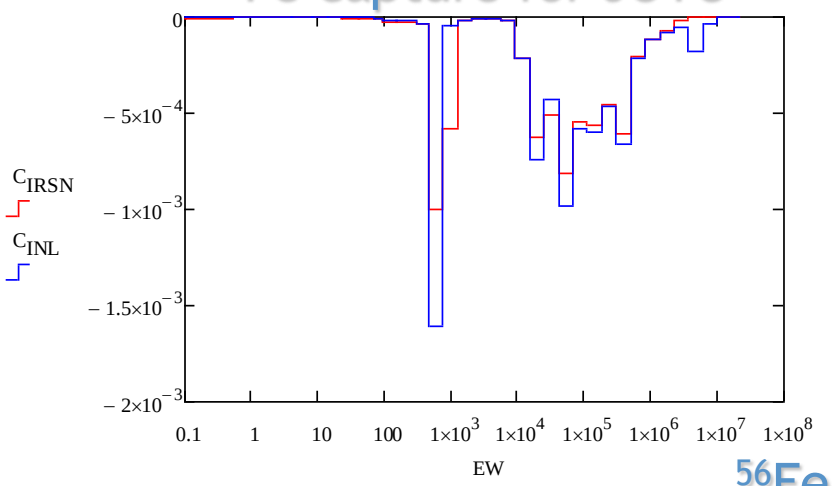
^{239}Pu inelastic for ABR



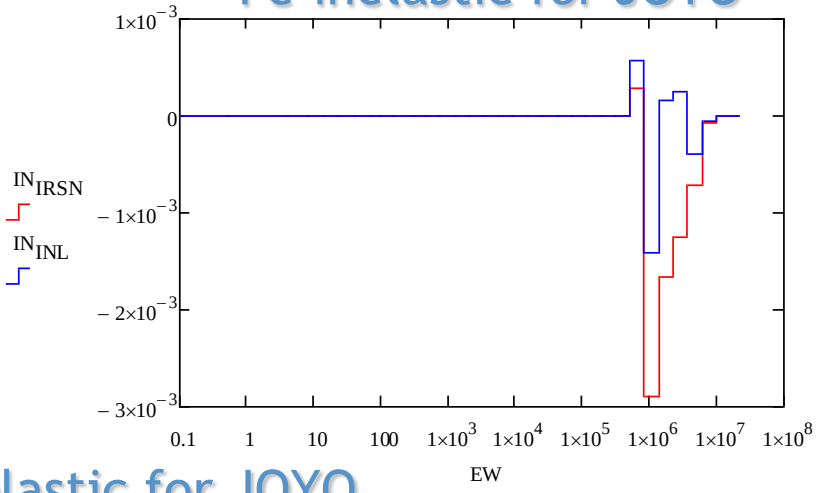
Data for Adjustment: k_{eff} Sensitivities

Comparison of TSUNAMI-3D/IRSN results (238 ->33 groups) with ERANOS/INL results (33 groups)

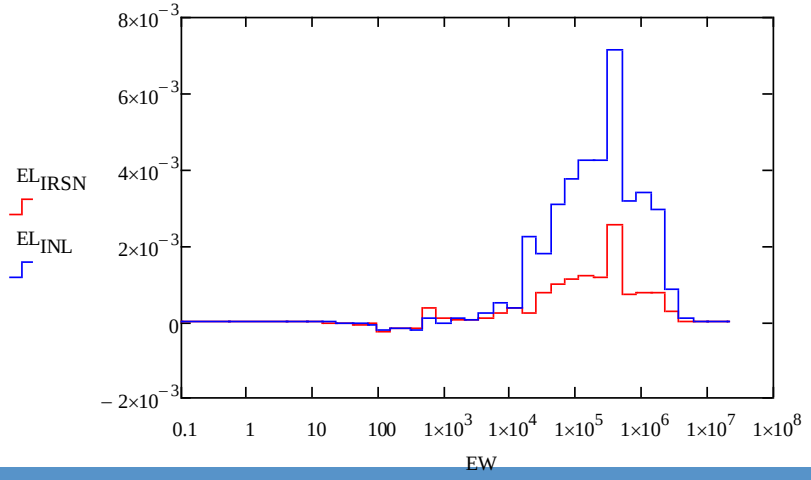
^{56}Fe capture for JOYO



^{56}Fe inelastic for JOYO



^{56}Fe elastic for JOYO



Data for Adjustment: k_{eff} Sensitivities

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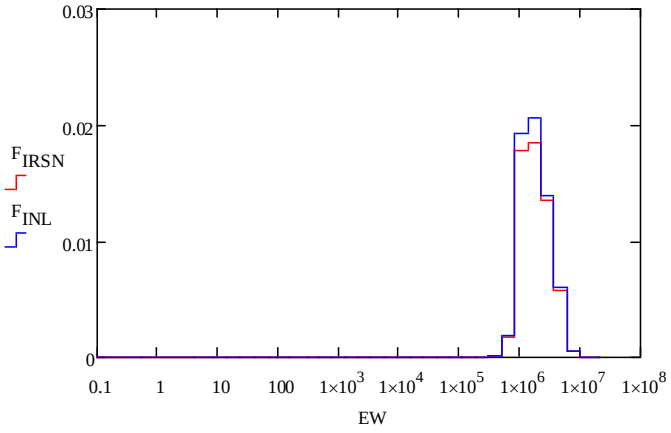
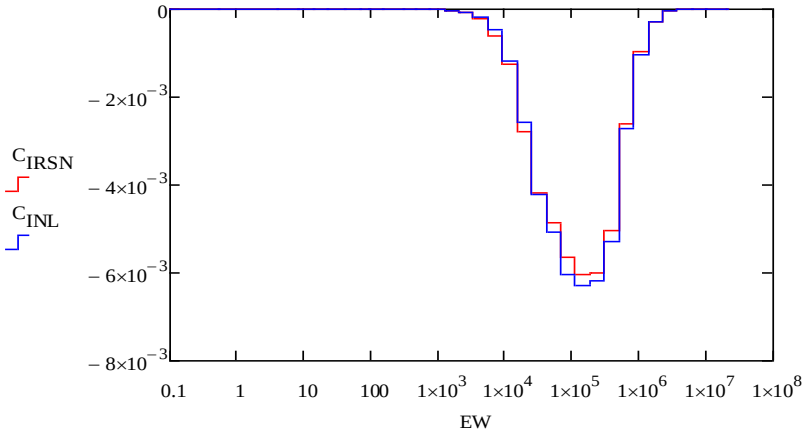
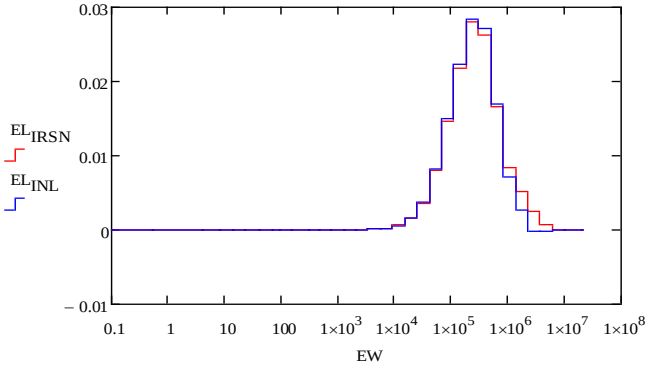
^{238}U fission for FLATTOP-Pu



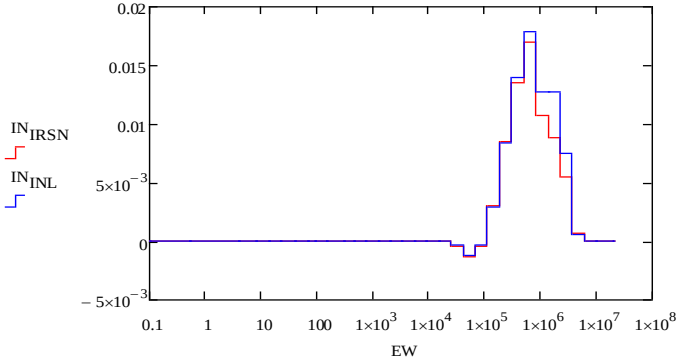
^{238}U capture for FLATTOP-Pu



^{238}U elastic for FLATTOP-Pu



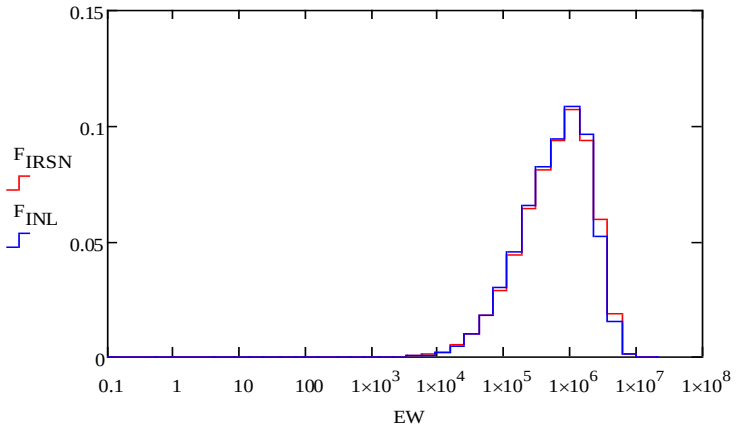
^{238}U inelastic for FLATTOP-Pu



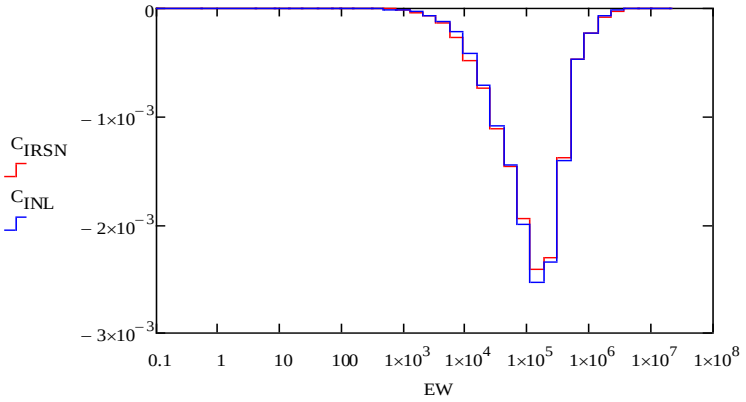
Data for Adjustment: k_{eff} Sensitivities

Comparison of TSUNAMI-3D/IRSN results (238 ->33 groups) with ERANOS/INL results (33 groups)

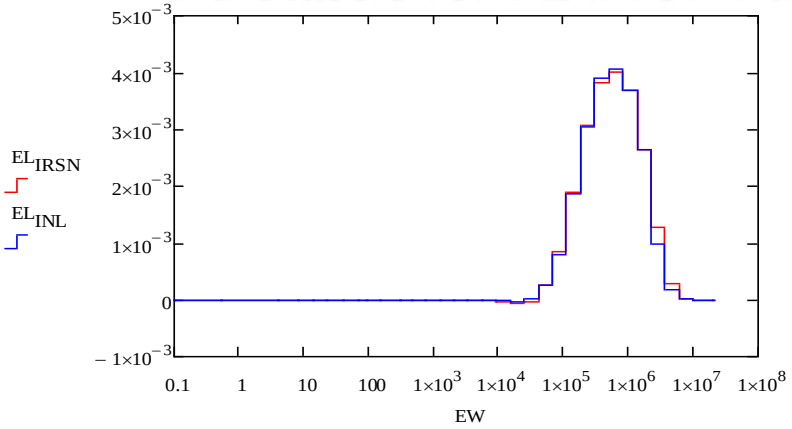
^{239}Pu fission for FLATTOP-Pu



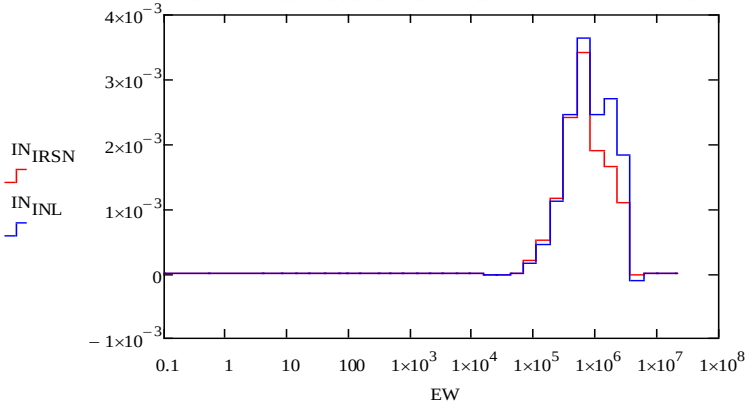
^{239}Pu capture for FLATTOP-Pu



^{239}Pu elastic for FLATTOP-Pu

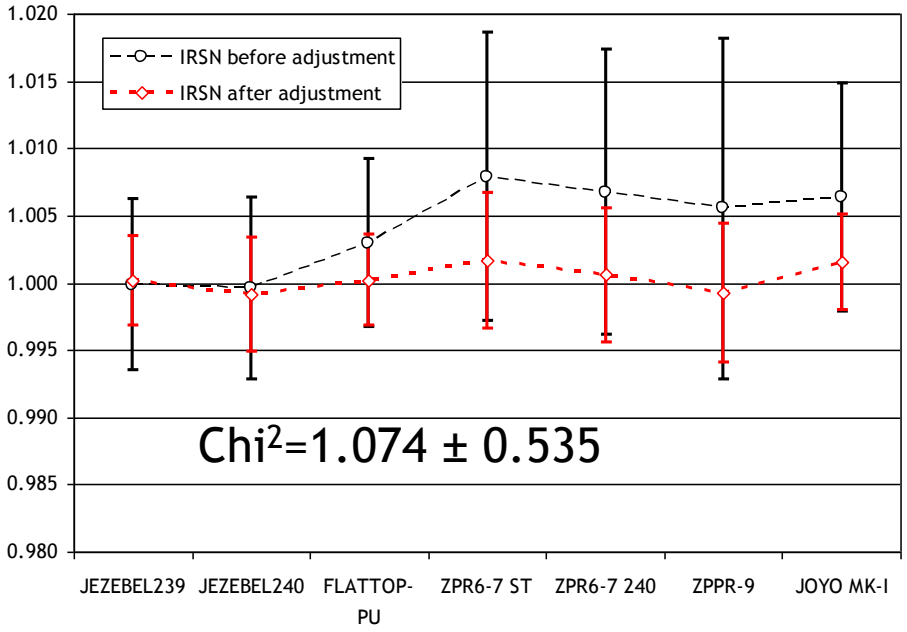


^{239}Pu inelastic for FLATTOP-Pu

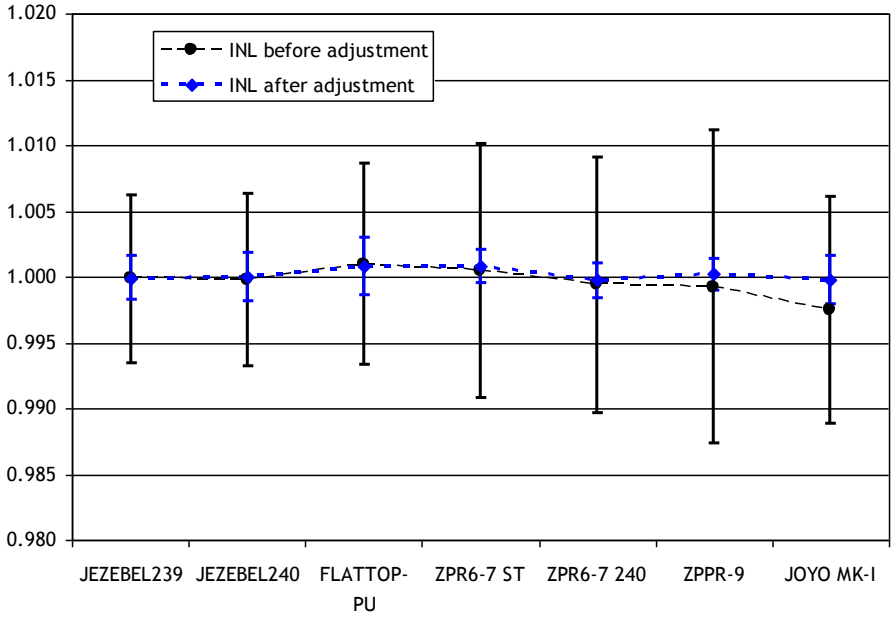


C/E and Uncertainties Before and After Adjustment

Only k-eff values



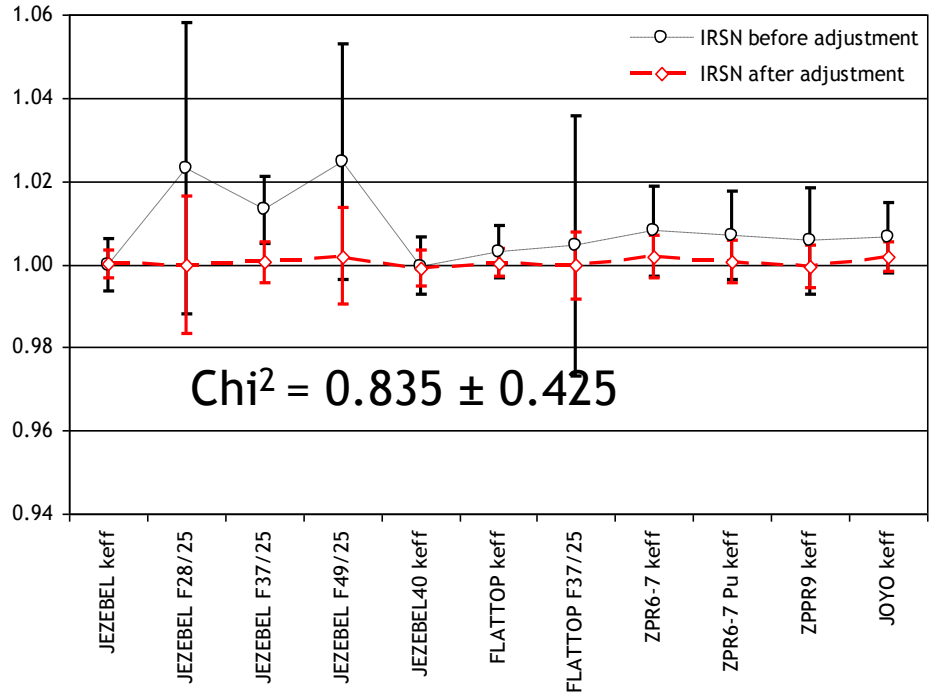
IRSN

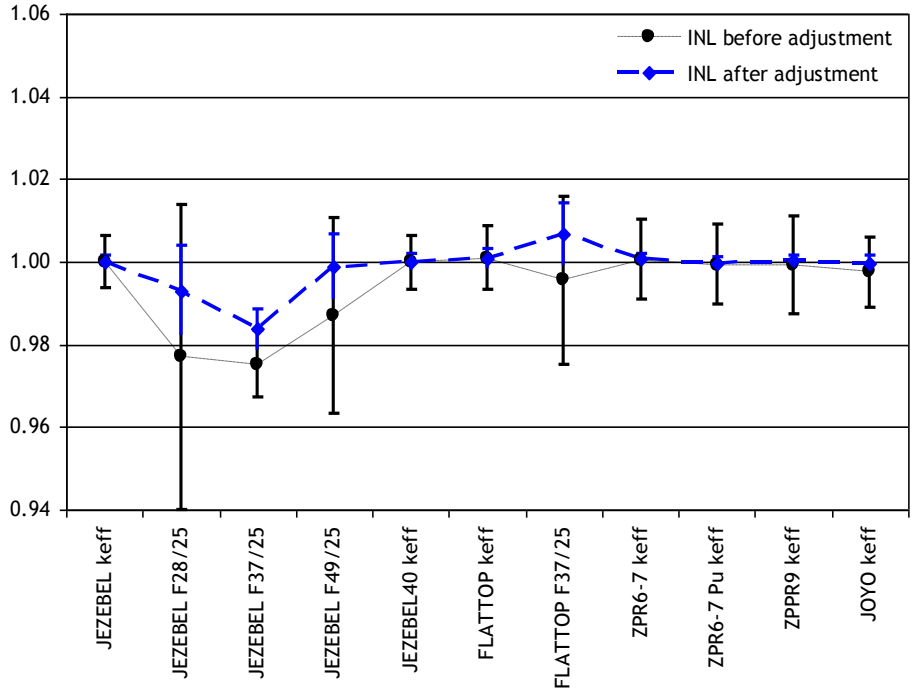


INL

C/E and Uncertainties Before and After Adjustment

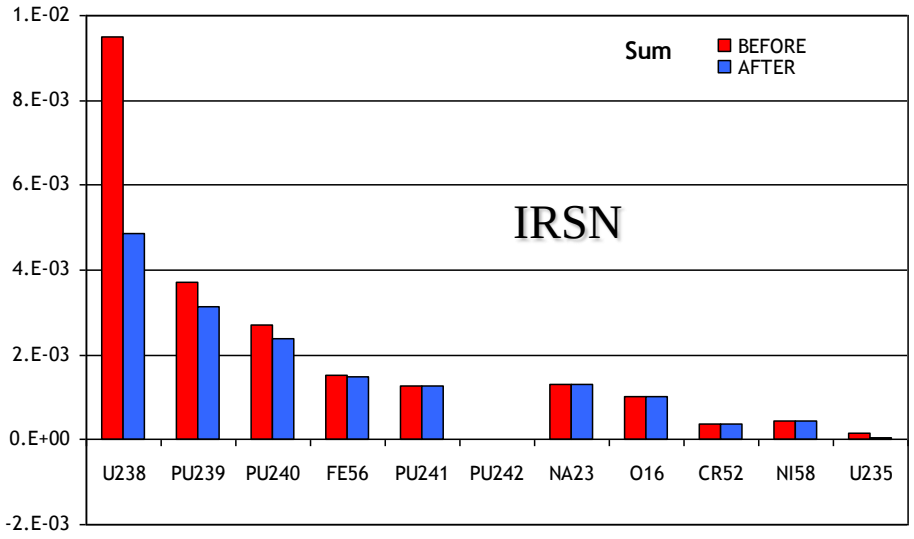
7 k-eff values and 3 reaction rates

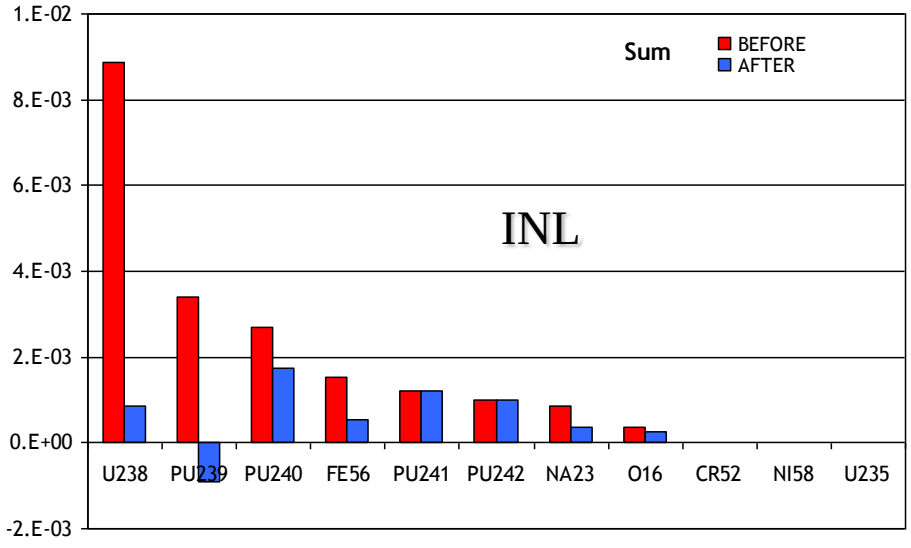




k_{eff} Uncertainties Before/After Adjustment

FBR





1.09% → 0.68% k_{eff} uncertainty

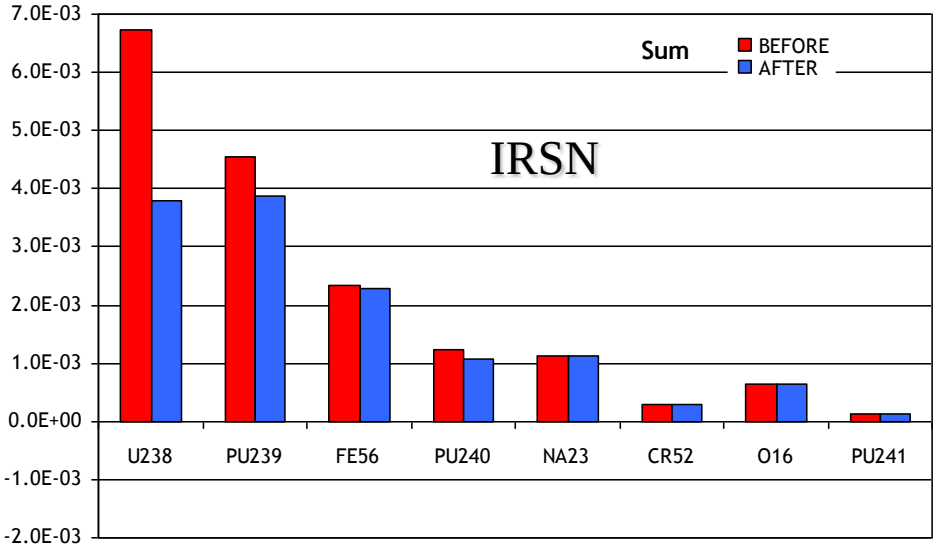
1. 01% → 0.24% k_{eff} uncertainty

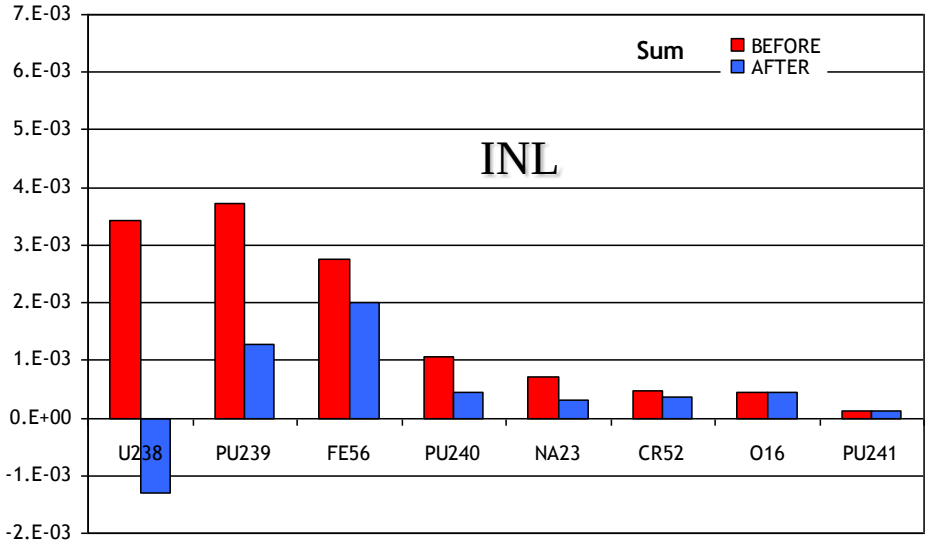
IRSN: TSUNAMI-1D, -3D sensitivities, COMMARA covariances, 7 k_{eff} values

INL: ERANOS sensitivities, COMMARA covariances, 20 parameters (k_{eff}, RR and Na void)

k_{eff} Uncertainties Before/After Adjustment

ABR





0. 86% → 0.61% k_{eff} uncertainty

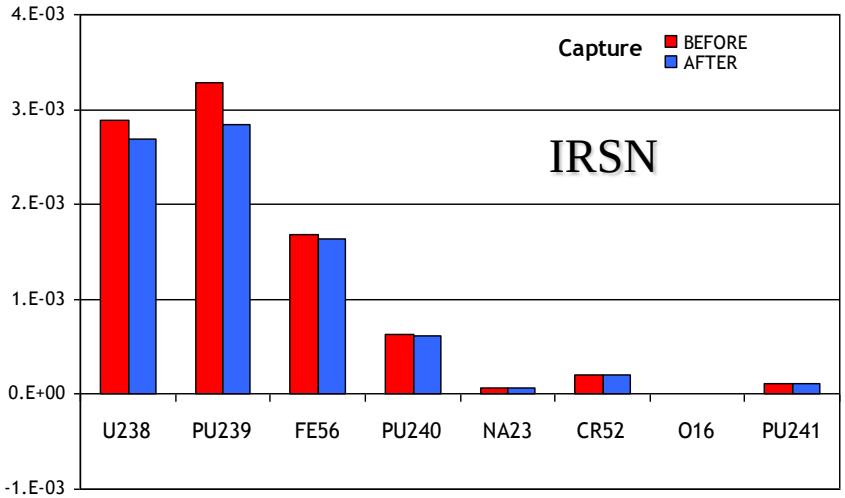
0. 60% → 0.21% k_{eff} uncertainty

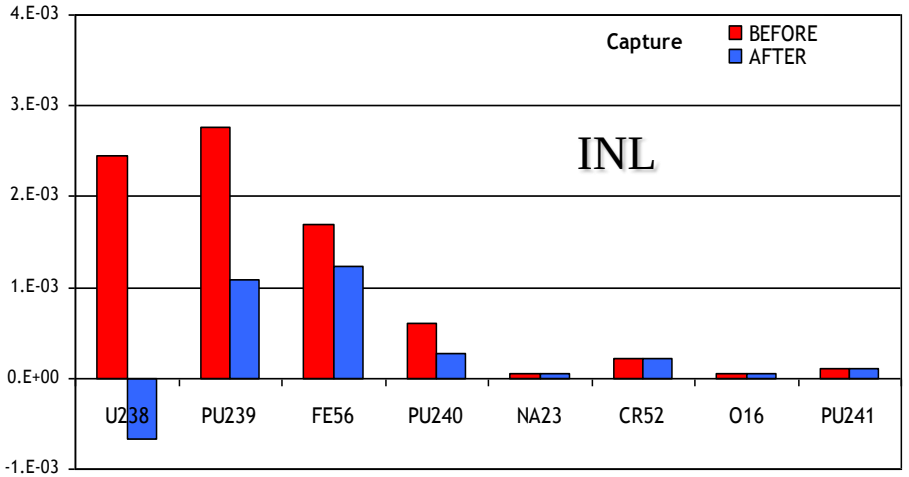
IRSN: TSUNAMI-1D, -3D sensitivities, COMMARA covariances, 7 k_{eff} values

INL: ERANOS sensitivities, COMMARA covariances, 20 parameters (k_{eff}, RR and Na void)

k_{eff} Uncertainties Before/After Adjustment

ABR Capture



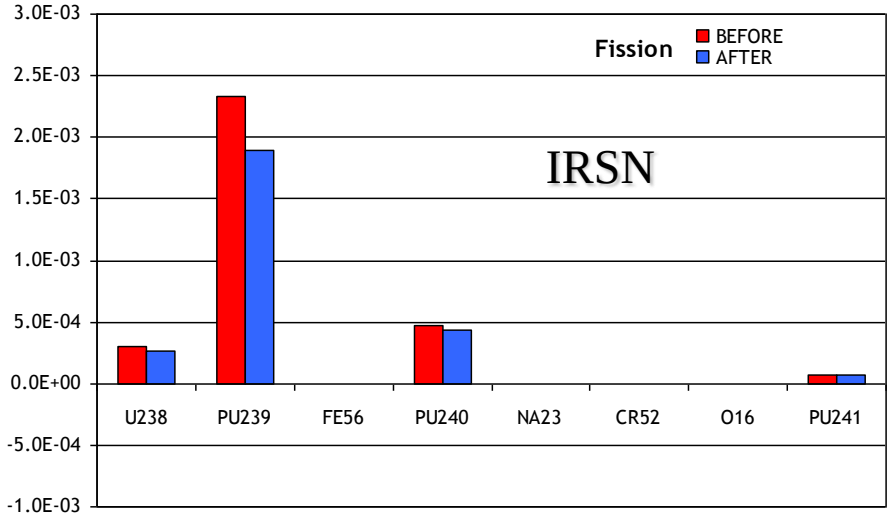


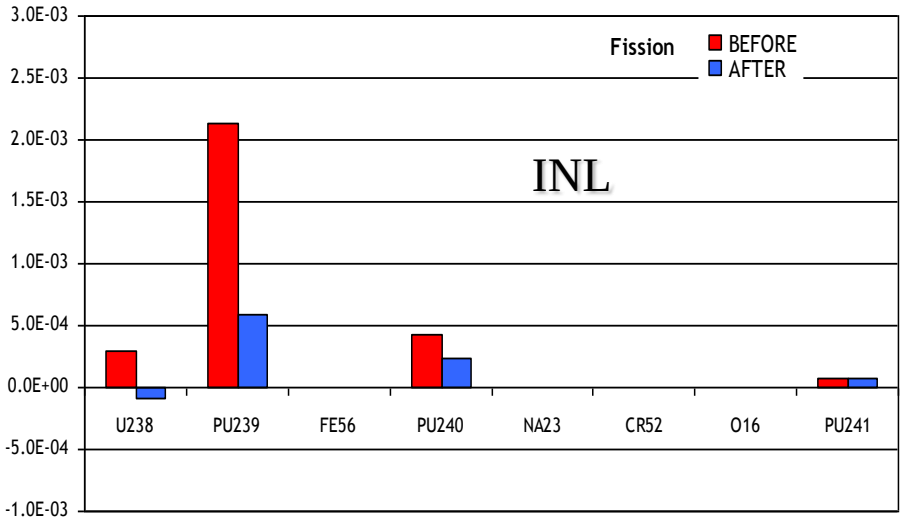
IRSN: TSUNAMI-1D, -3D sensitivities, COMMARA covariances, 7 k_{eff} values

INL: ERANOS sensitivities, COMMARA covariances, 20 parameters (k_{eff}, RR and Na void)

k_{eff} Uncertainties Before/After Adjustment

ABR Fission



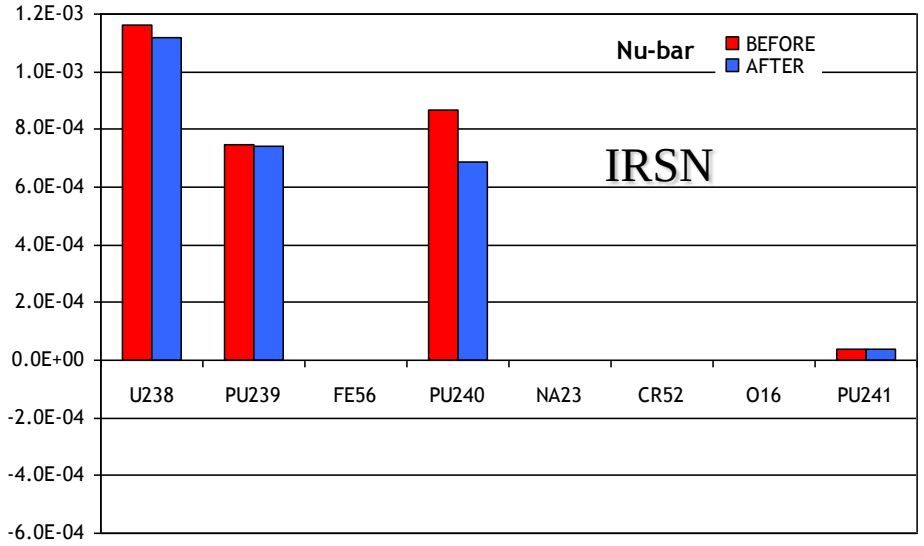


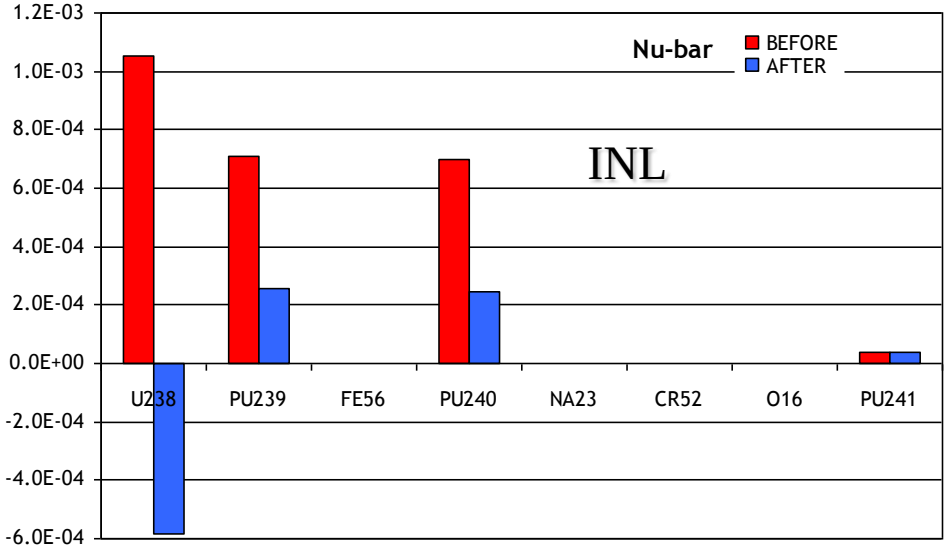
IRSN: TSUNAMI-3D sensitivities, COMMARA covariances, 7 k_{eff} values

INL: ERANOS sensitivities, COMMARA covariances, 20 parameters (k_{eff}, RR and Na void)

k_{eff} Uncertainties Before/After Adjustment

ABR Nu-bar



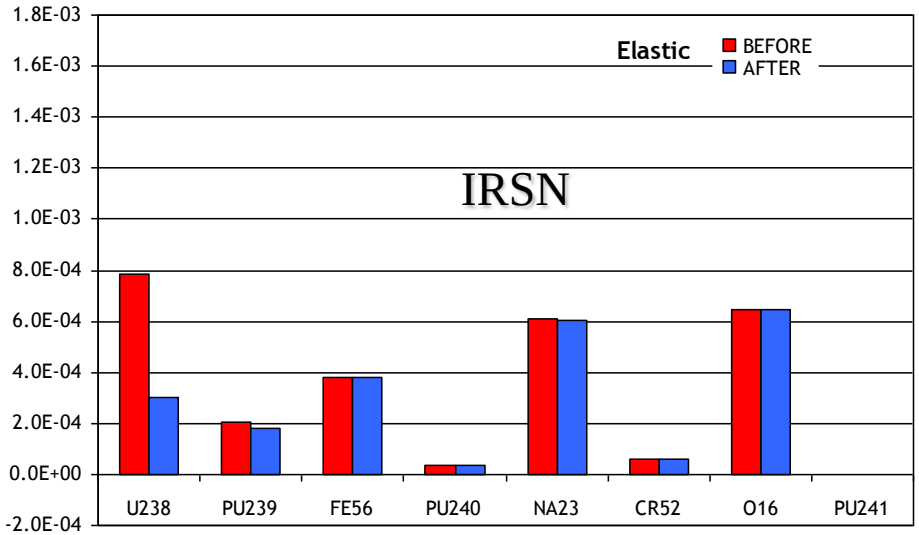


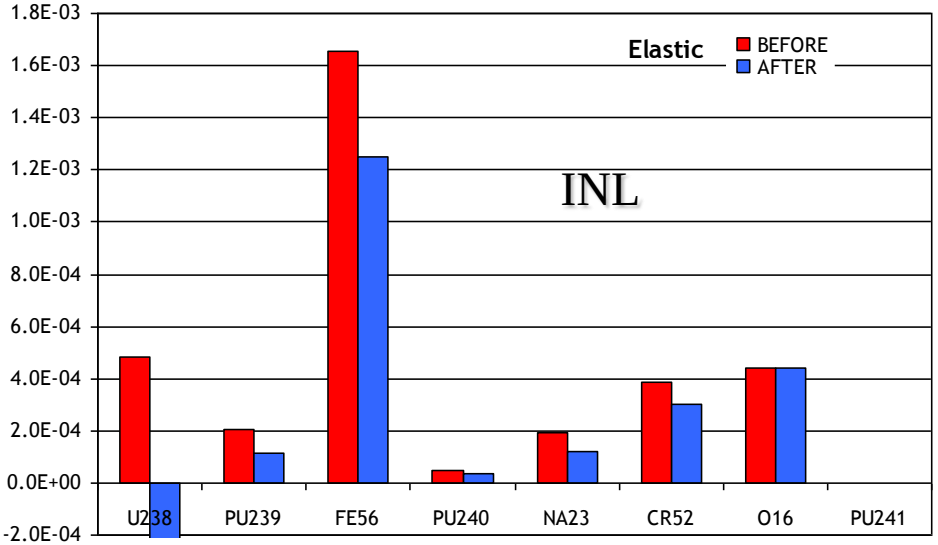
IRSN: TSUNAMI-1D, -3D sensitivities, COMMARA covariances, 7 k_{eff} values

INL: ERANOS sensitivities, COMMARA covariances, 20 parameters (k_{eff}, RR and Na void)

k_{eff} Uncertainties Before/After Adjustment

ABR Elastic



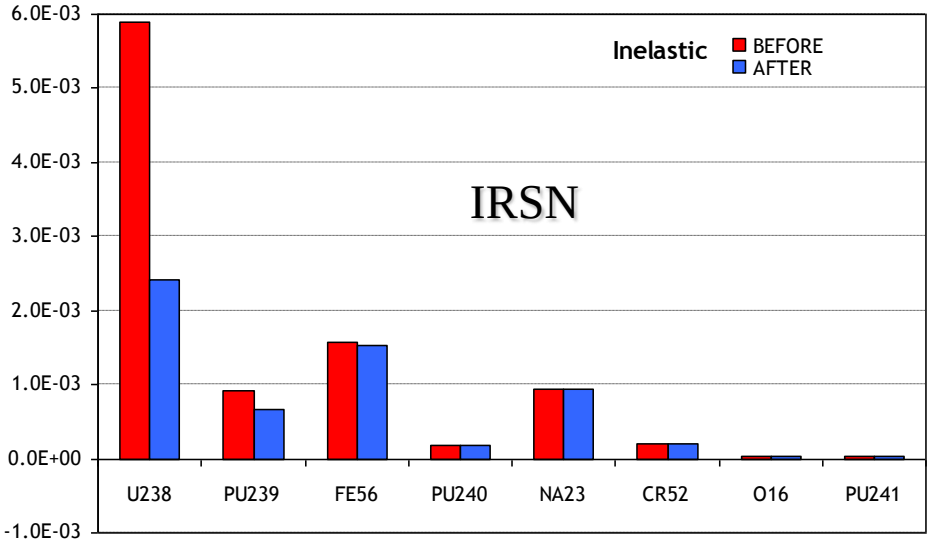


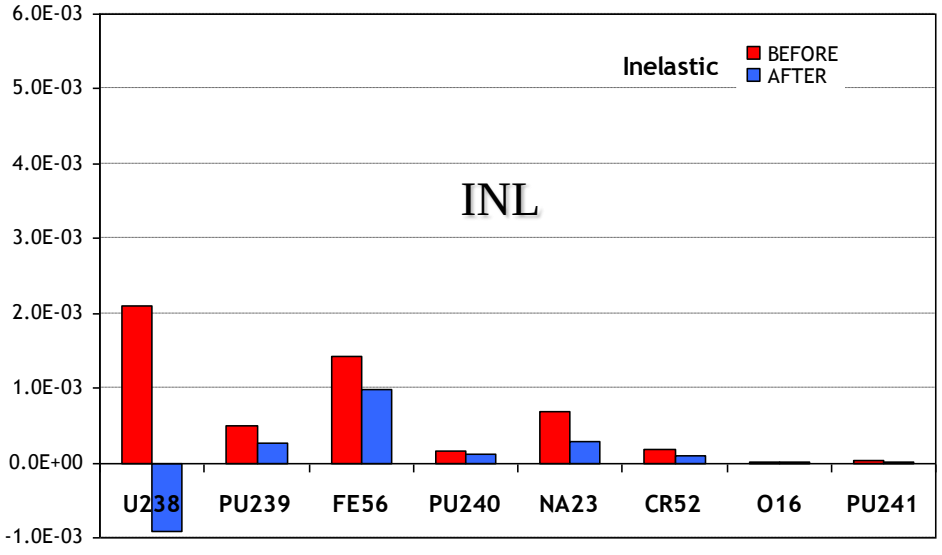
IRSN: TSUNAMI-1D, -3D sensitivities, COMMARA covariances, 7 k_{eff} values

INL: ERANOS sensitivities, COMMARA covariances, 20 parameters (k_{eff}, RR and Na void)

k_{eff} Uncertainties Before/After Adjustment

ABR Inelastic



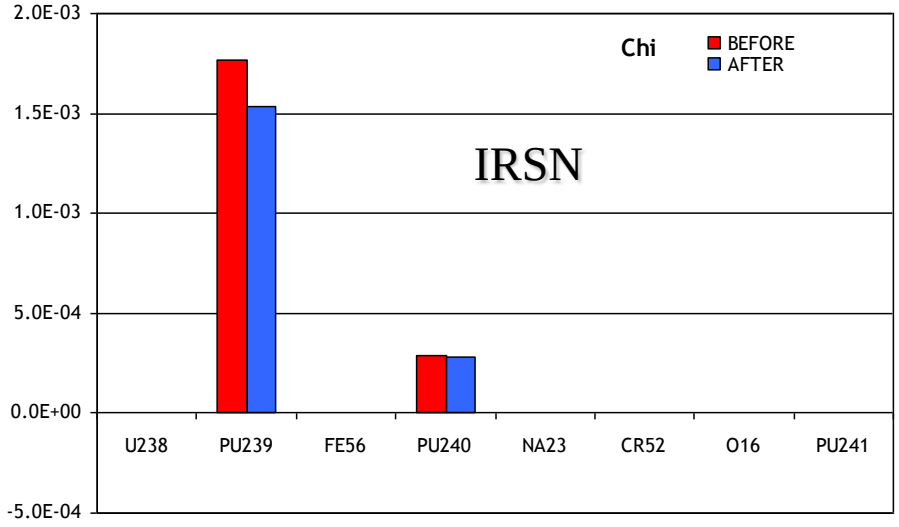


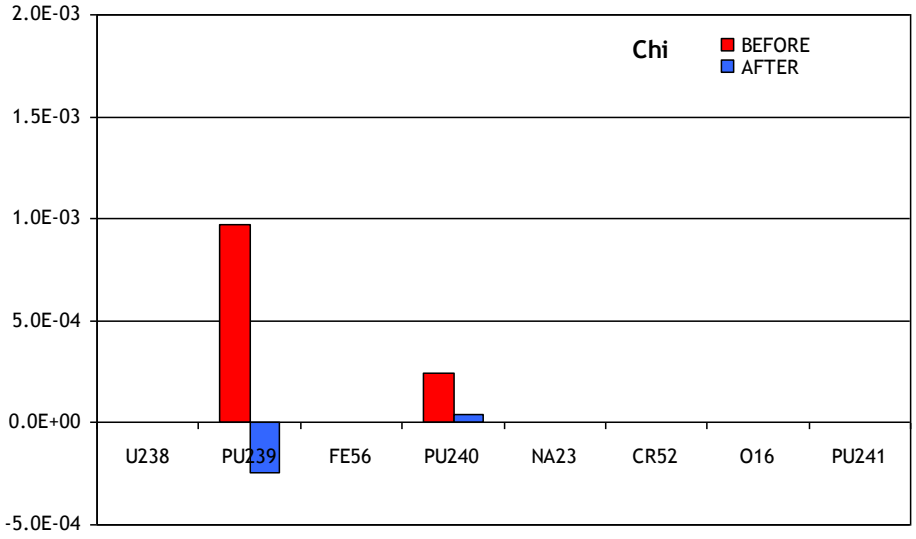
IRSN: TSUNAMI-1D, -3D sensitivities, COMMARA covariances, 7 k_{eff} values

INL: ERANOS sensitivities, COMMARA covariances, 20 parameters (k_{eff}, RR and Na void)

k_{eff} Uncertainties Before/After Adjustment

ABR Chi



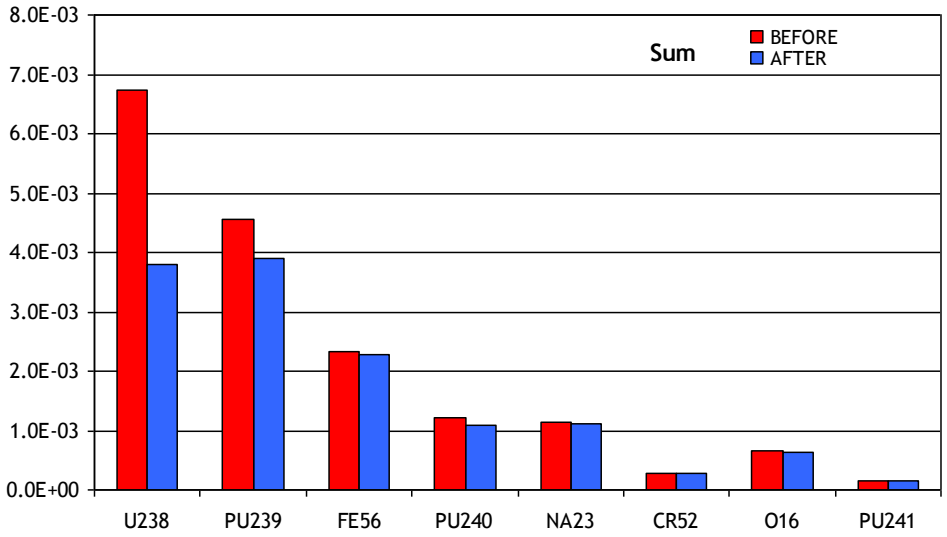


IRSN: TSUNAMI-1D, -3D sensitivities, COMMARA covariances, 7 k_{eff} values

INL: ERANOS sensitivities, COMMARA covariances, 20 parameters (k_{eff}, RR and Na void)

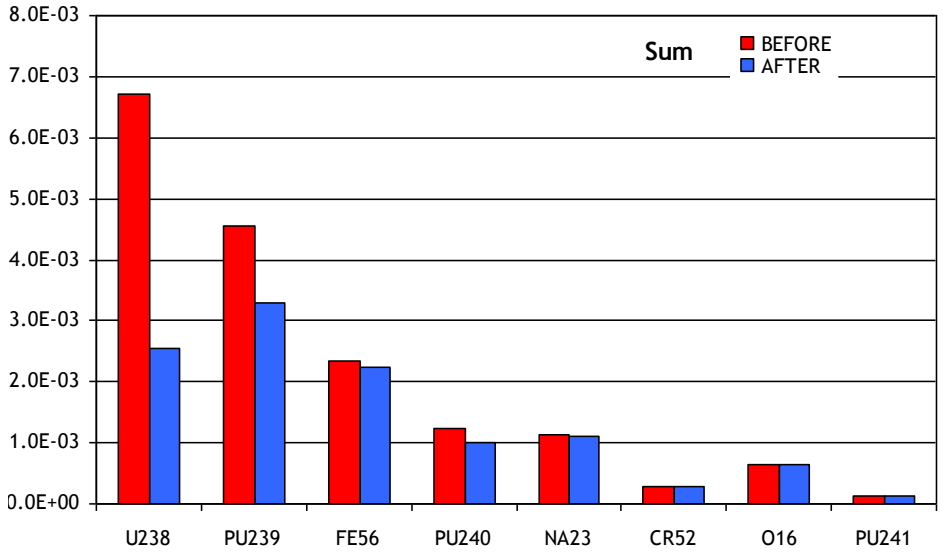
k_{eff} Uncertainties Before/After Adjustment

ABR



7 k_{eff} values

0.86% → 0.61% k_{eff} uncertainty

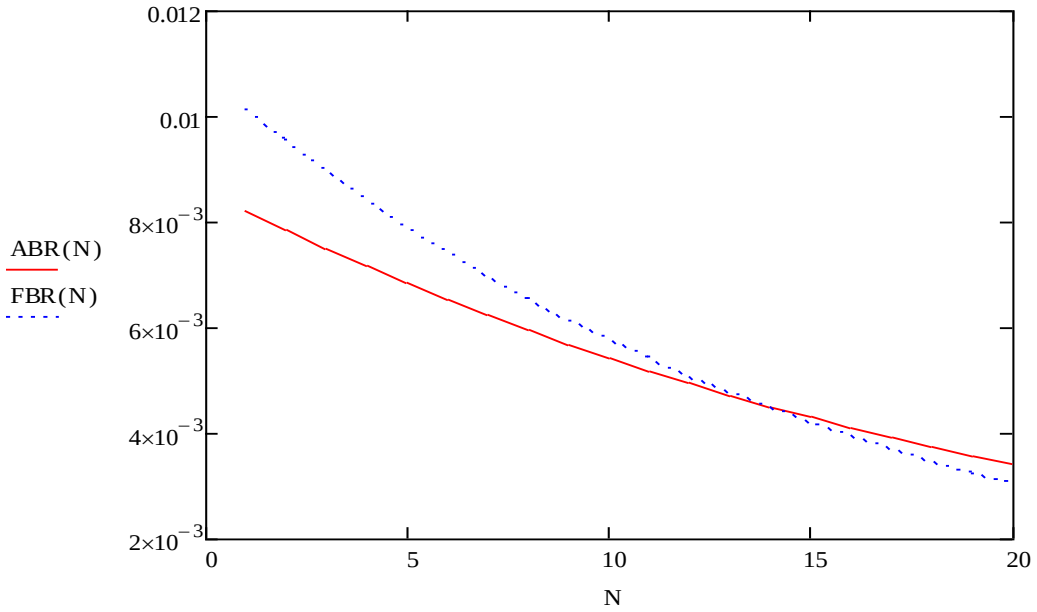


7 k_{eff} values + 3RR

0.86% → 0.50% k_{eff} uncertainty

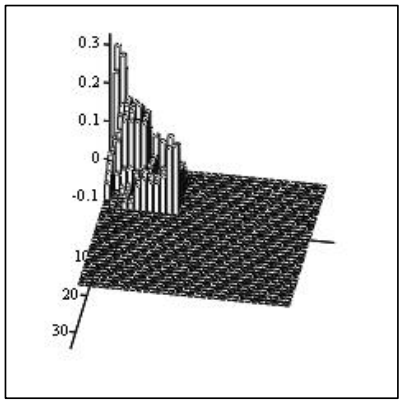
Uncertainty Reduction as Function of a Number of Benchmarks

$$ABR(N) := \exp(\alpha_0)\cdot\exp(\alpha_1\cdot N^{\varepsilon}) \qquad FBR(N) := \exp(\beta_0)\cdot\exp(\beta_1\cdot N^{\varepsilon})$$



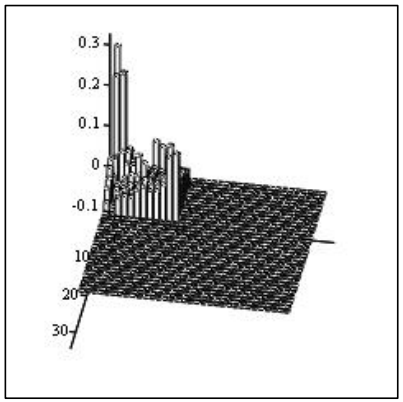
$$ABR(20) = 3.415\times 10^{-3} \qquad FBR(20) = 3.065\times 10^{-3}$$

^{238}U Inelastic Covariances and Uncertainties for ABR



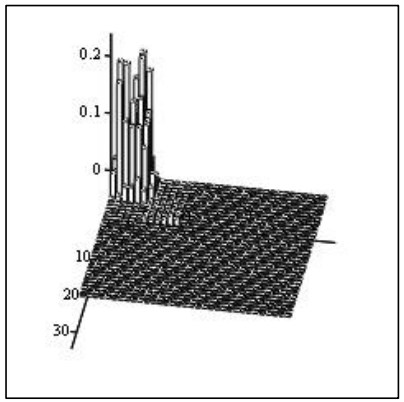
M4

BEFORE



m4

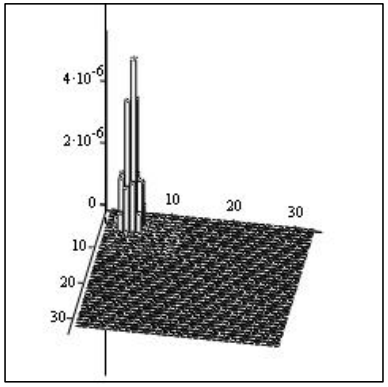
AFTER



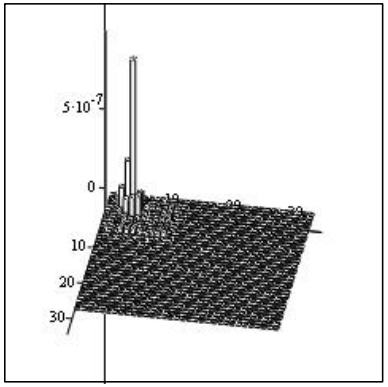
M4 – m4

BEFORE -AFTER

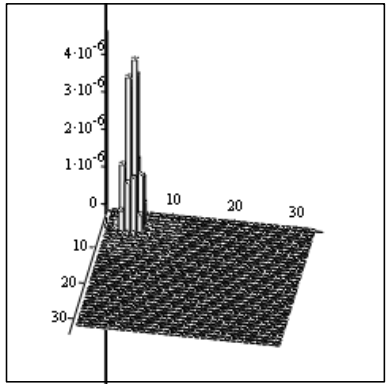
Covariance matrices for ^{238}U inelastic scattering



II



ii

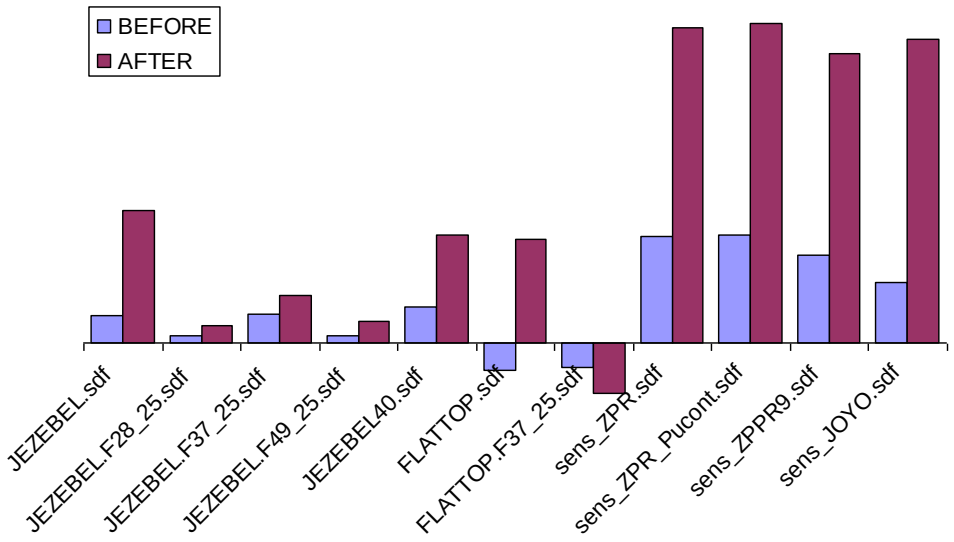


II – ii

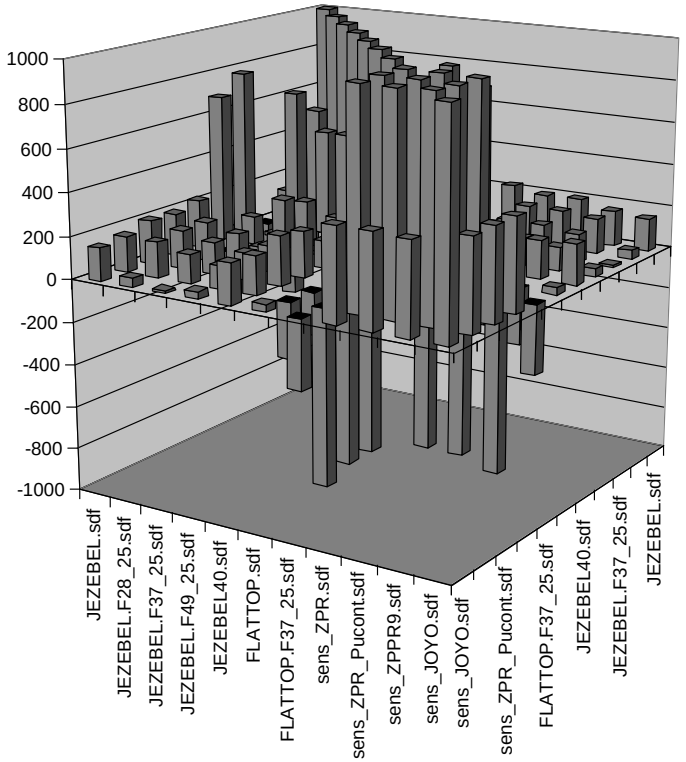
ABR Oxide Core k_{eff} uncertainty due to the covariances for ^{238}U inelastic scattering

Benchmarks' Representativities and Correlations

Representativitiy factors relative to ABR



Correlations due to ND uncertainties



$$R_{i,j} = \frac{\left(\vec{S}_i^{\,T} \cdot Cov \cdot \vec{S}_j\right)}{\sqrt{\left(\vec{S}_i^{\,T} \cdot Cov \cdot \vec{S}_i\right) \cdot \left(\vec{S}_j^{\,T} \cdot Cov \cdot \vec{S}_j\right)}}$$

Discussion: Sensitivities

- For this exercise, condensation of TSUNAMI-1D, -3D sensitivities from 238 groups to 33 groups was done with weight of energy intervals
- Correctness of the condensation was checked and proved
- Sensitivities were computed with TSUNAMI-1D and -3D for Jezebels. 1D results were used for the adjustment
- Unconstrained sensitivities for **chi** were used for this exercise
- Preliminary comparison with INL results shows that sensitivity are notably different for ^{238}U and ^{56}Fe scattering (elastic and inelastic)

Discussion: Adjustment

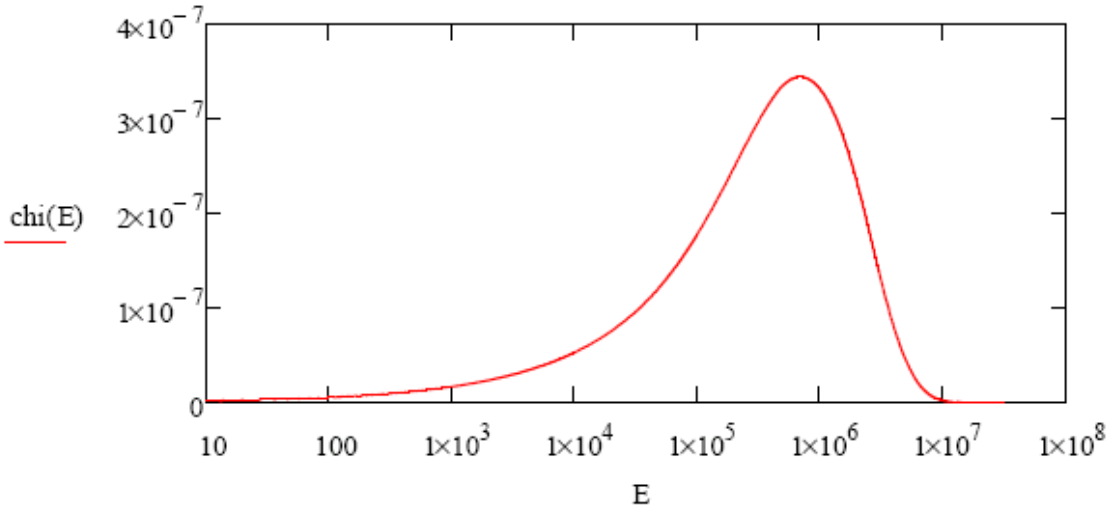
- BERING code created recently at IRSN was used for the adjustment
- The adjustment was applied to k_{eff} only
- Chi^2 criterion is about unity for all adjustment cases
- The obtained results are difficult to compare with other contributions since only 7(10) of 20 parameters were used for the adjustment
- This exercise is an excellent opportunity to test the code performance as well as quality of input data for the code

Further Work for This Exercise

- Understand difference in calculated parameters and sensitivities
- Use other sensitivity sequences (direct perturbation) for computations
- Use ERANOS results for adjustment
- Add missing parameters (RR and Sodium void)
- Perform stress test
- Add other covariances, i.e., TENDL, JENDL…

Cross correlation appearance of the nuclear data, χ and ν example

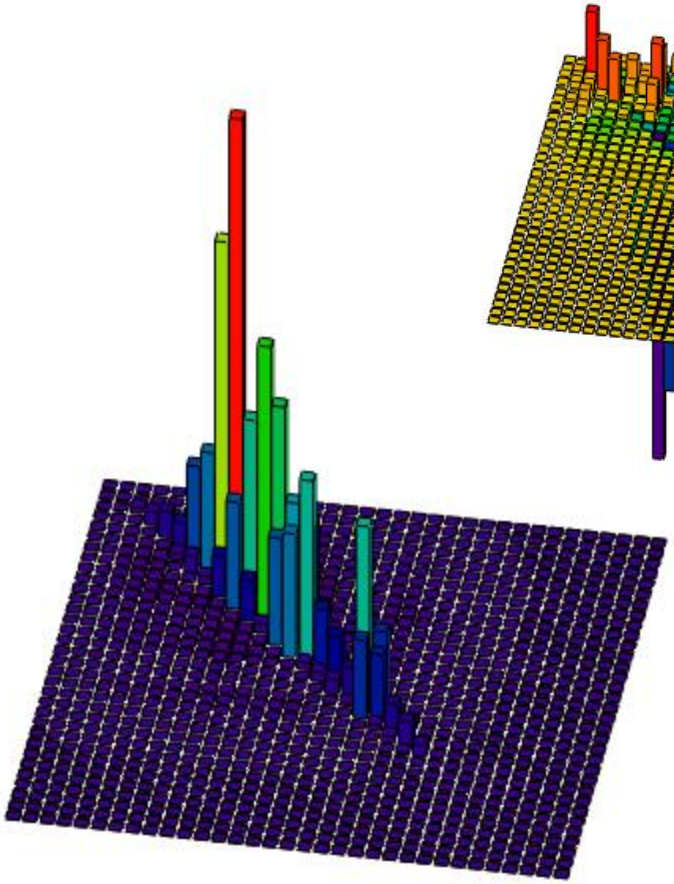
$$\chi(E) = \frac{2 \cdot \exp(-\frac{a \cdot b(\nu)}{4})}{a \cdot \sqrt{\pi \cdot a \cdot b(\nu)}} \cdot \exp(-\frac{E}{a}) \cdot sh(\sqrt{b(\nu) \cdot E})$$



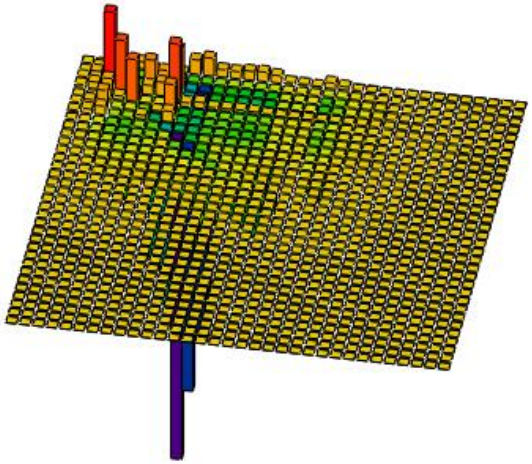
The idea of the numerical experiment:

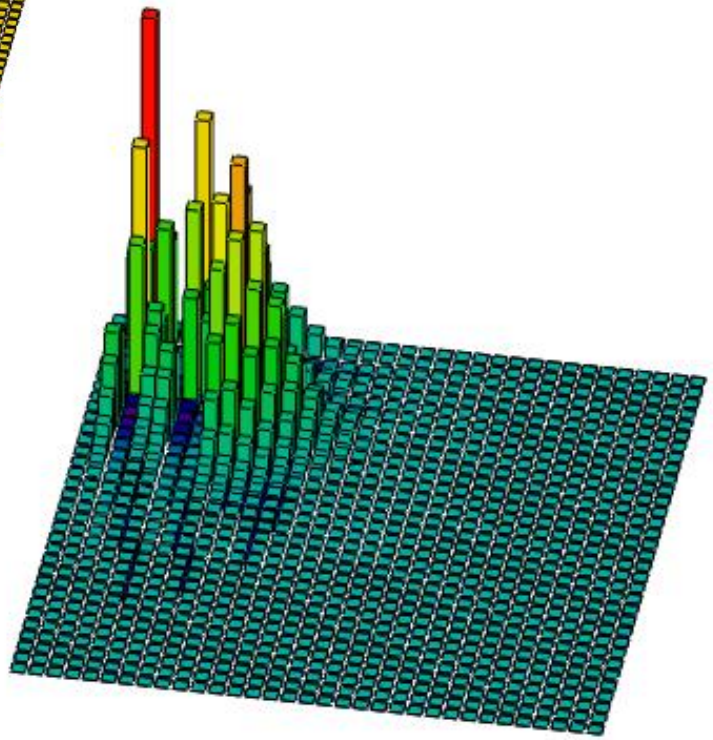
- *Selection of the relevant experimental based integral benchmarks*
- *Generation of the hypothetical cross-correlation matrices for ν-bar and χ_p*
- *Derivation of the cross-covariance by adjustment procedure*

Cross correlation appearance of the nuclear data, χ and ν example, numerical experiment



ν-bar





χ_p