Comparison of deterministic and Monte Carlo sensitivity analysis of SNEAK-7A and FLATTOP-Pu Benchmarks

Ivo Kodeli, Manuele Aufiero, Winfried Zwermann

SG39 Meeting, NEA, Nov. 27-28, 2014

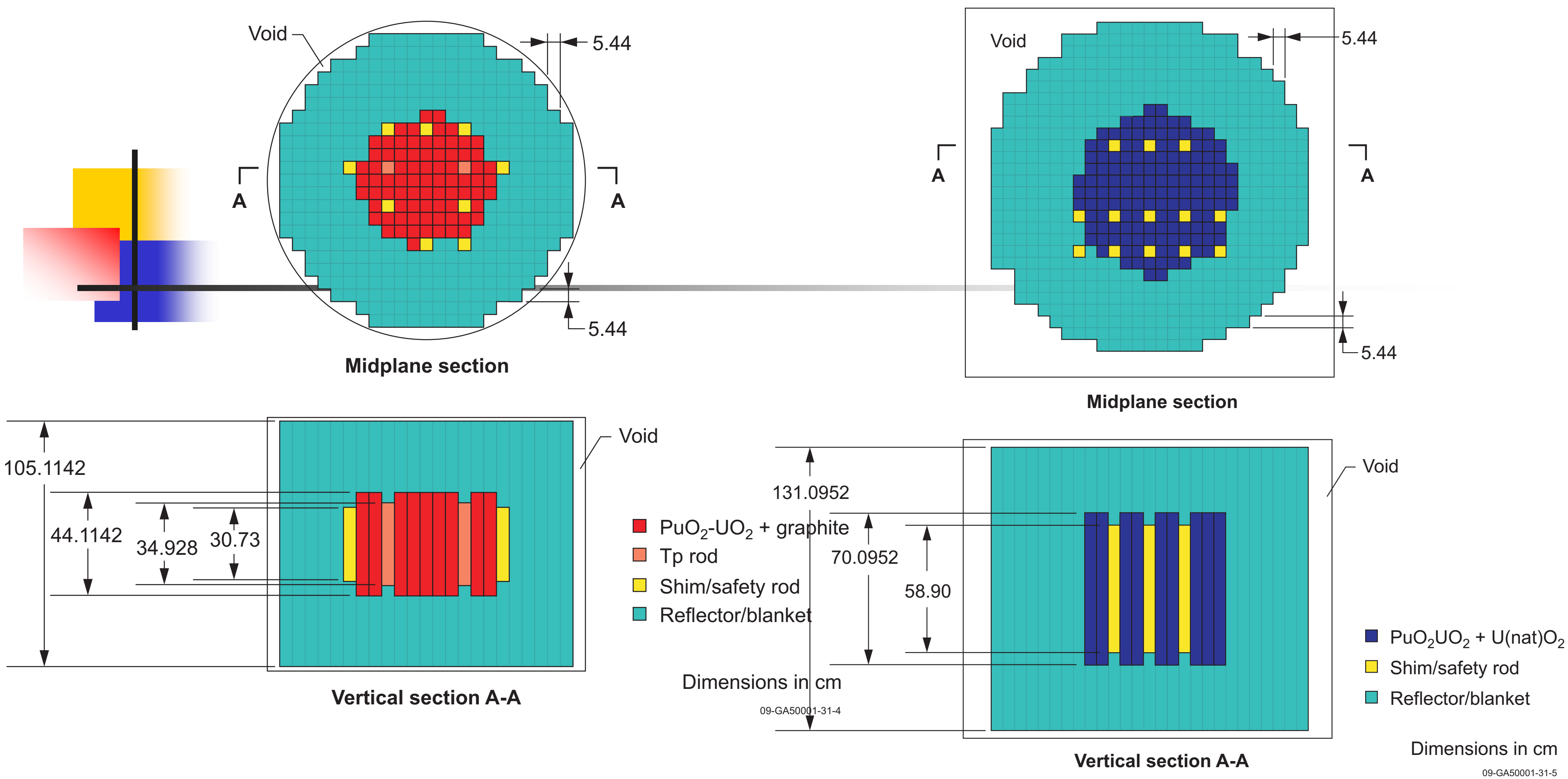
V. Mastrangelo, I. Kodeli, E. Sartori, Proposal of a Benchmark for Stochastic and Deterministic Analyses of Nuclear Data Sensitivities and Uncertainties, UAM Workshop, Pisa, April 2006

- Fast reactor benchmarks SNEAK-7A & 7B (Karlsruhe Fast Critical Facility), re-evaluated using detailed 3-D models in the framework of the International Reactor Physics Benchmark Experiments (IRPhE) project, were proposed to test and compare state-of-the-art cross section sensitivity and uncertainty codes.

Reference: NEA/NSC/DOC(2006)1 March 2009 Edition – IRPhE Handbook (Evgeny Ivanov, IRSN, CNAM, IPN)

http://irphep.inl.gov/handbook/hbrequest.shtml

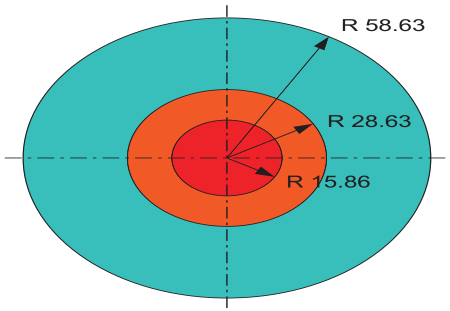
- Calculate the sensitivity of k_{eff} and β_{eff} to the nuclear cross sections and the corresponding uncertainties.
- Compare and analyse results from different methods and codes for consistency and identify and explain discrepancies.



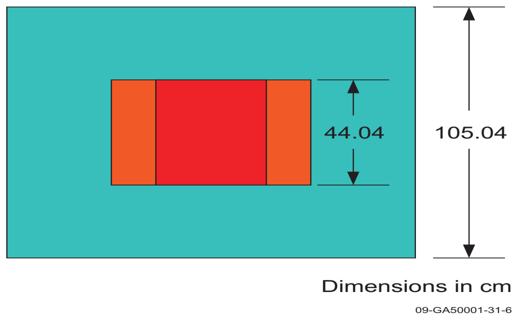
SNEAK-7A and -7B fast critical experiments (detailed&simplified 3D models).

- SNEAK-7A core unit cell consisted of one PuO_2-UO_2 pellet (26,6% PuO_2 and 73,4% UO_2) and one graphite platelet. Radial and axial blankets were loaded with metallic depleted UO_2 plates.
- In SNEAK-7B the graphite platelets were replaced by $U_{nat}O_2$ platelet.
- The effective core radii of SNEAK-7A & 7B were 28.63 cm and 37.84 cm.

SNEAK 7A R-Z Model



R-Z model horizontal cut, SNEAK 7A



R-Z model vertical cut, SNEAK 7A

	SNEAK 7A	SNEAK 7B
β_{eff} - ^{252}Cf source measurements	0.00395 ± 5%	0.00429 ± 5%
β_{eff} – noise analysis	0.00413±6%	0.00450±6%
β_{eff} – benchmark values	**0.00395±5%**	**0.00429±6%**

Model		SNEAK 7A		SNEAK 7B	
		k_{eff}	σk_{eff}	k_{eff}	σk_{eff}
1	Detailed 3D model with stretched platelets	1.0010 (a)	0.0029 (b)	1.0016 (a)	0.0035 (b)
2	3D simplified model with homogenized core regions of fuel elements	0.9998 (c)	0.0029	1.0001 (c)	0.0035
3	RZ two-dimensional model	1.0038 (c)	0.0029	1.0028 (c)	0.0035

(a) Measured k_{eff}.
(b) Combined experimental uncertainty
(c) Equal to experimental value + (calculated simplified model – calculated more detailed model)

Contributed solutions

- *Winfried Zwermann: XSUSA*
- *Manuele Aufiero: SERPENT2 GPT extended*
- *Victor Mastrangelo: TSUNAMI 3D*
- *Yannick Peneliau, Cyrille De Saint Jean: PARIS & ERANOS*
- *Ivan Kodeli: SUSD3D*

Computational Methods and Procedures

k_{eff} and β_{eff} sensitivity:

Winfried Zwermann, GRS:

- ***XSUSA/TWODANT****, direct perturbation method, 2D*
- Cross sections: ENDF/B-VII

Manuele Aufiero, LPSC/CNRS:

- ***SERPENT2*** *with extended GPT option, 2D* ,
- Cross sections: JEFF 3.1.1 and ENDF/B-VII, probability tables

Ivo Kodeli, IJS Ljubljana

- Neutronic and sensitivity code: **SUSD3D** with PARTISN/TWODANT/THREEDANT
- Cross sections: 33-group ENDF/B-VII.0, S_8P_3, processed by NJOY99
- 2D and 3D models

Evgeny Ivanov, IRSN (ongoing)

- MCNP6

k_{eff} sensitivity:

Victor Mastrangelo (retired from CNAM and IPN-Orsay)

- Neutronic and sensitivity code: **TSUNAMI-3D**;
- Cross sections: 238-group ENDF/B-VII, P_5S_8

Yannick Peneliau, Cyrille De Saint Jean, CEA Cadarache

- Neutronics & sensitivity codes: **ERANOS** and **PARIS**; 2D model
- Cross sections: Ecco+Sn2d with JEFF 3.1.1 and ENDF/B-VII (33 groups)
- Sensitivities to cross-sections, total nu-bar and fission spectra

Sensitivity of k_{eff} to $\sigma_{U\text{-}238}$

k_{eff} / ^{238}U	Sensitivity of k-eff **to** ^{238}**U** (%/%)					
	Elastic	Inelastic	(n,f)	(n,abs)	ν_{tot}	ν_{del}
SUSD3D/2D	$1.02\cdot10^{-1}$	$-1.69\cdot10^{-2}$	$8.70\cdot10^{-2}$	$-1.58\cdot10^{-1}$	$1.37\cdot10^{-1}$	$1.81\cdot10^{-3}$
XSUSA	$9.75\cdot10^{-2}$	$-1.63\cdot10^{-2}$				$2.10\cdot10^{-3}$
SERPENT	$1.03\cdot10^{-1}$	$-1.67\cdot10^{-2}$	$8.5\cdot10^{-2}$	$-1.64\cdot10^{-1}$	$1.33\cdot10^{-1}$	$1.92\cdot10^{-3}$
TSUNAMI /preliminary	$-2.13\cdot10^{-3}$	$-4.88\cdot10^{-2}$	$6.76\cdot10^{-2}$	$-1.32\cdot10^{-1}$	$1.12\cdot10^{-1}$	
SUSD3D/1D	$-1.88\cdot10^{-1}$	$-5.50\cdot10^{-2}$	$7.64\cdot10^{-2}$	$-1.46\cdot10^{-1}$	$1.25\cdot10^{-1}$	$1.70\cdot10^{-3}$
SUSD3D/3D	$1.01\cdot10^{-1}$	$-1.75\cdot10^{-2}$	$8.78\cdot10^{-2}$	$-1.61\cdot10^{-1}$	$1.38\cdot10^{-1}$	$1.83\cdot10^{-3}$

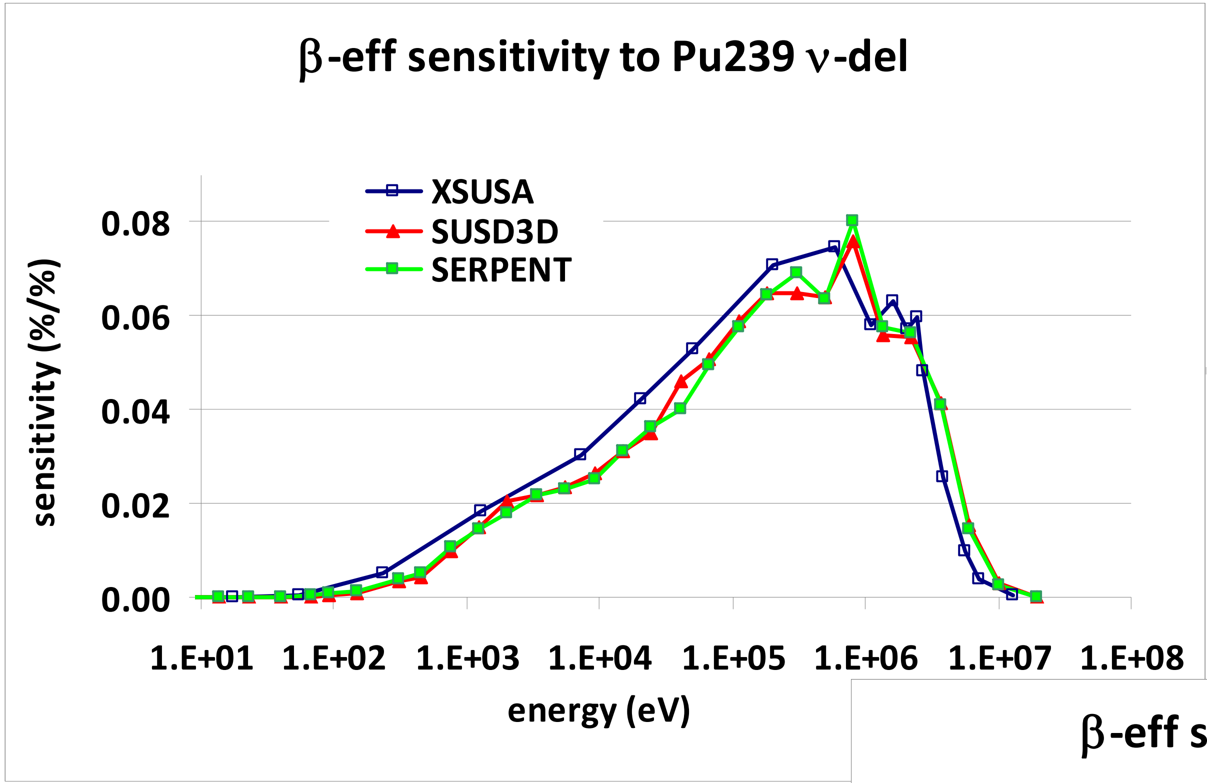
Sensitivity of β_{eff} to $\sigma_{U\text{-}238}$

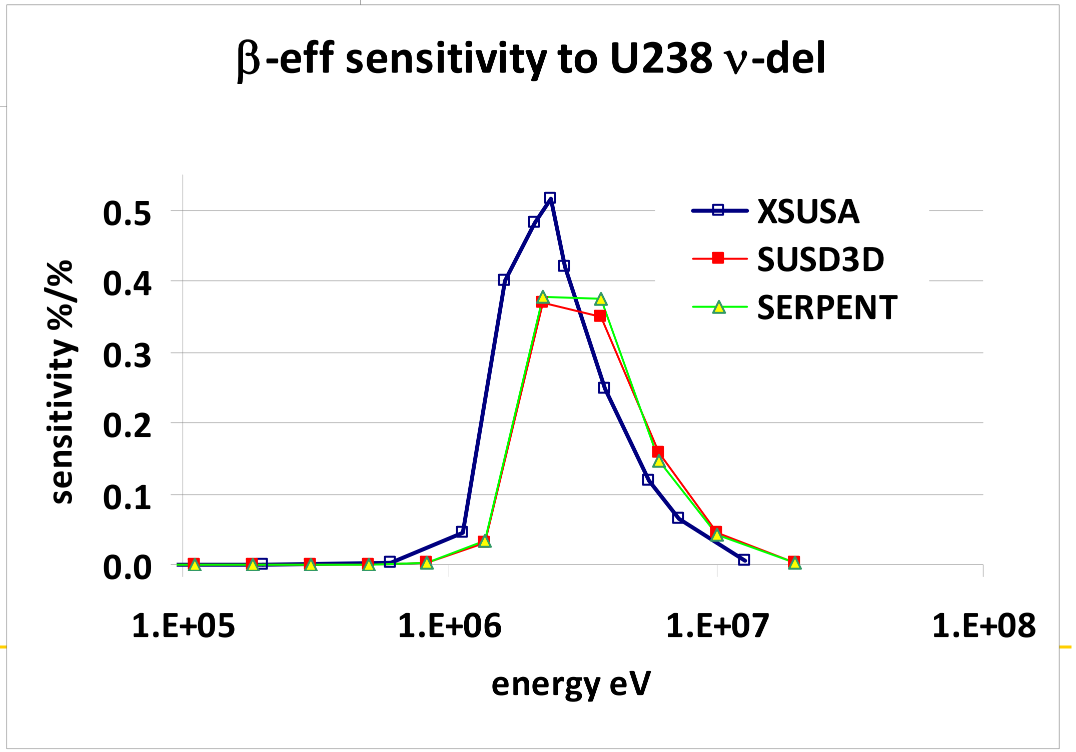
β_{eff} / ^{238}U	Sensitivity of β**-eff to ^{238}U** (%/%)					
	Elastic	Inelastic	(n,f)	(n,abs)	ν_{tot}	ν_{del}
SUSD3D	-0.011	-0.151	0.276	-0.017	0.255	0.488
XSUSA	-0.022	-0.165				0.531
SERPENT/J31	-0.013±47%	-0.138±1.3%	0.274±0.4%	-0.03±4.6%	0.246±0.4%	0.492±0.1%
SERPENT/B7	-0.018±58%	-0.127±3.0%	0.261±0.4%	-0.03±4.7%	0.231±0.4%	0.479±0.1%

Uncertainties

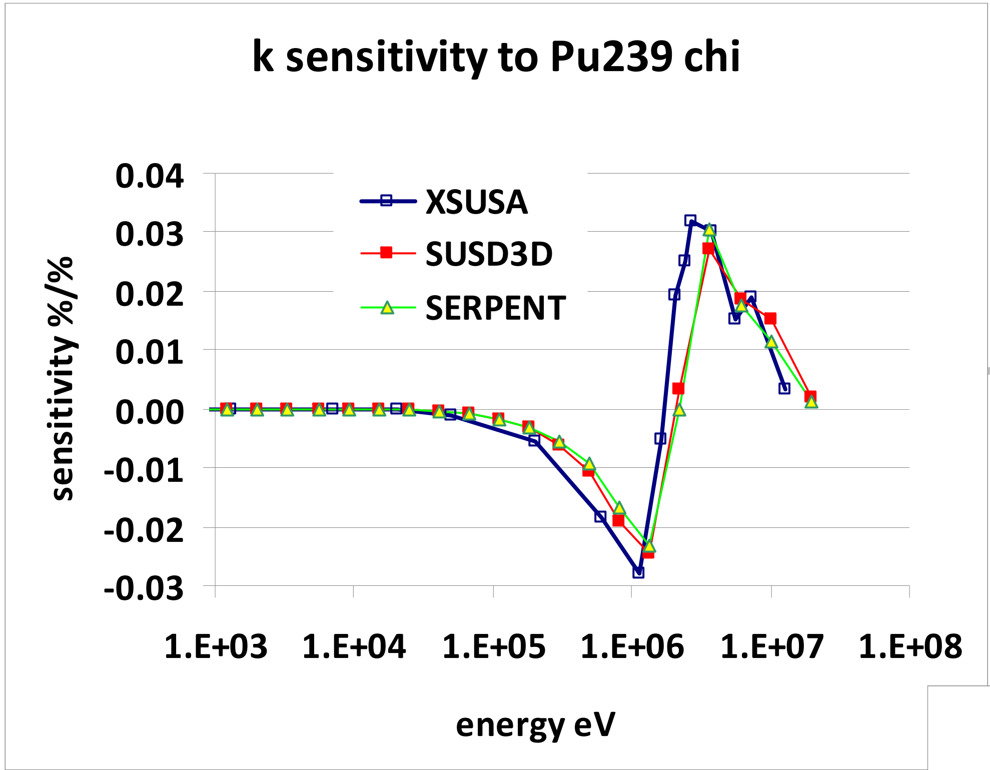
Code	Covariances	k_{eff}	Δk_{eff}	β_{eff} (pcm)	$\Delta\beta_{eff}$
XSUSA	SCALE6 + ν_{del} from JENDL4.0	1.01385	0.61%	394	Direct 3.9% Random sampling: 4.0%
SUSD3D	JENDL-4.0 COMMARA-2 Commara+J4	2D: 1.00733 3D: 1.00659	0.62%	373	2.7 % 2.6 % 3.4 %
SERPENT JEFF3.1 ENDF/BVII	/	1.00691±1pcm 1.00721±3pcm		385.4±0.5 373.5 ± 2	

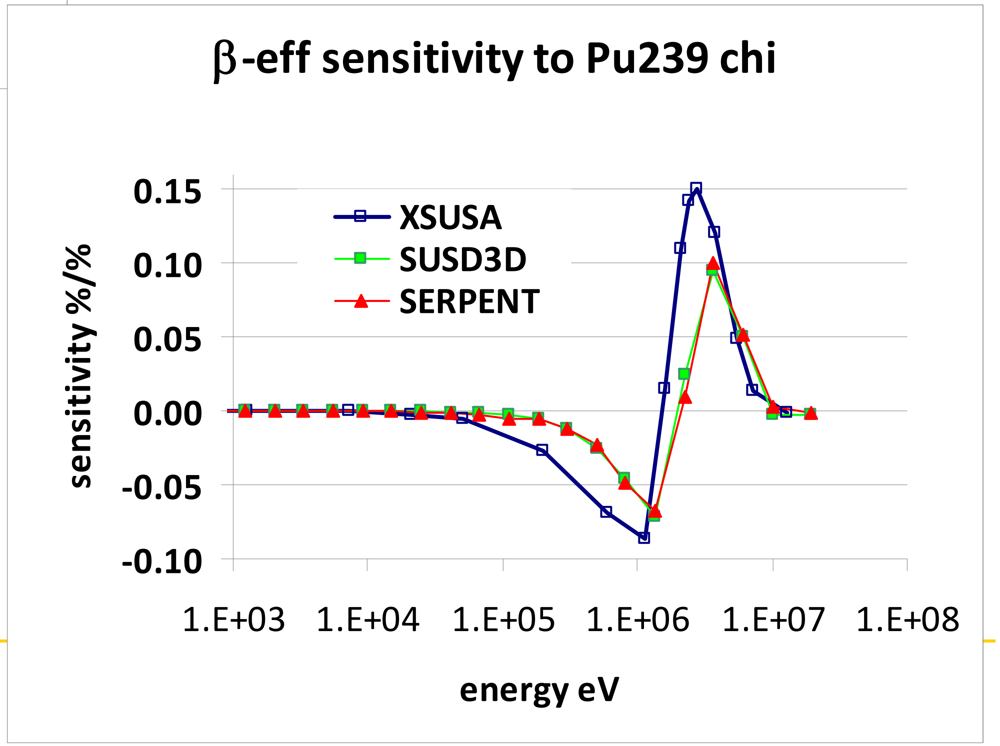
SNEAK-7A (SUSD3D – XSUSA - SERPENT)



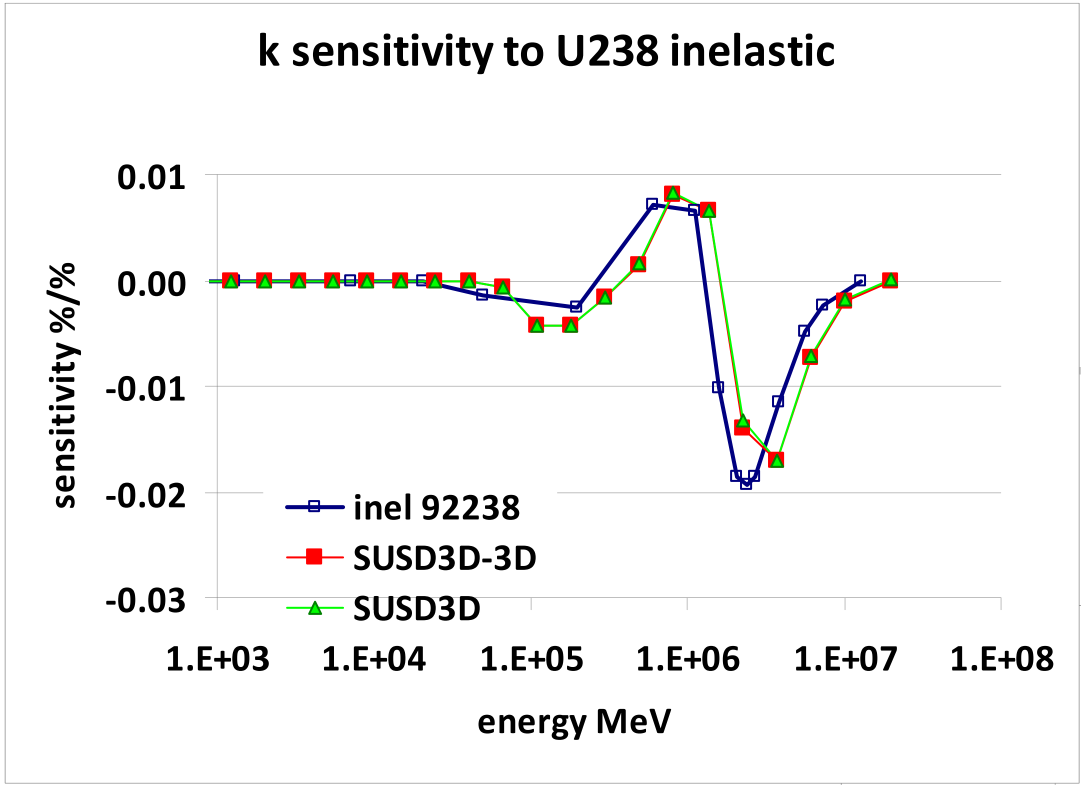


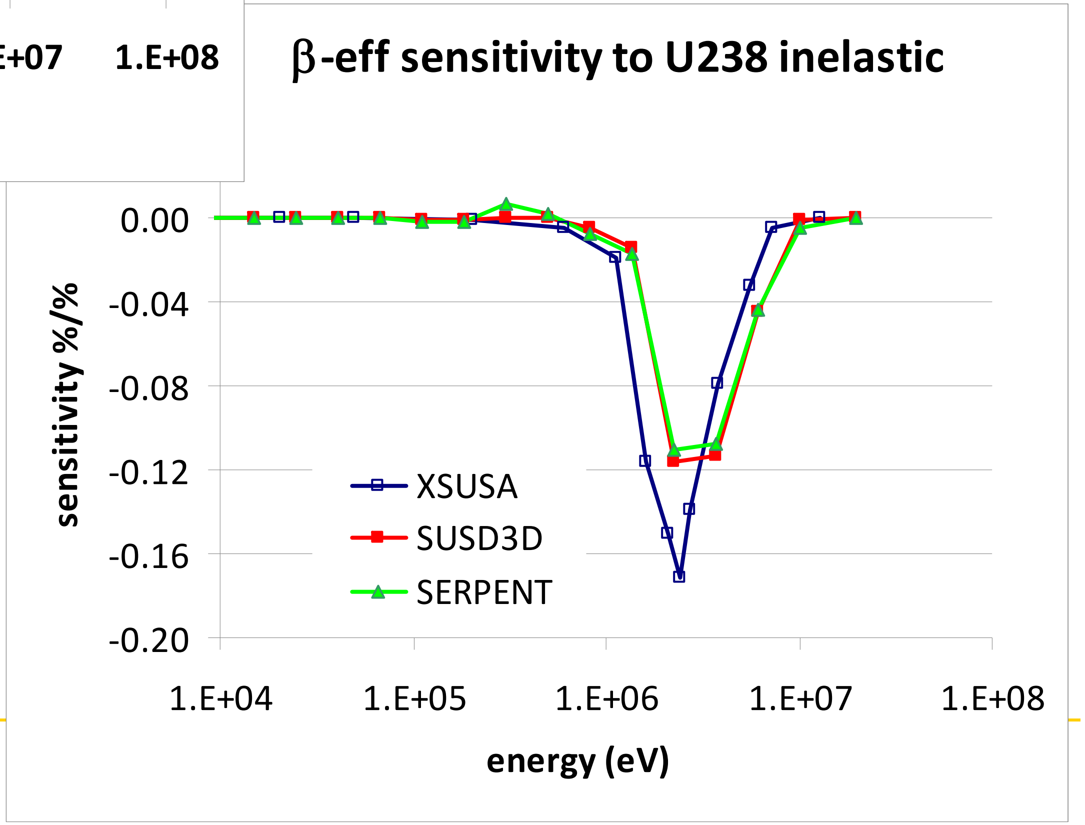
SNEAK-7A (SUSD3D – XSUSA - SERPENT)



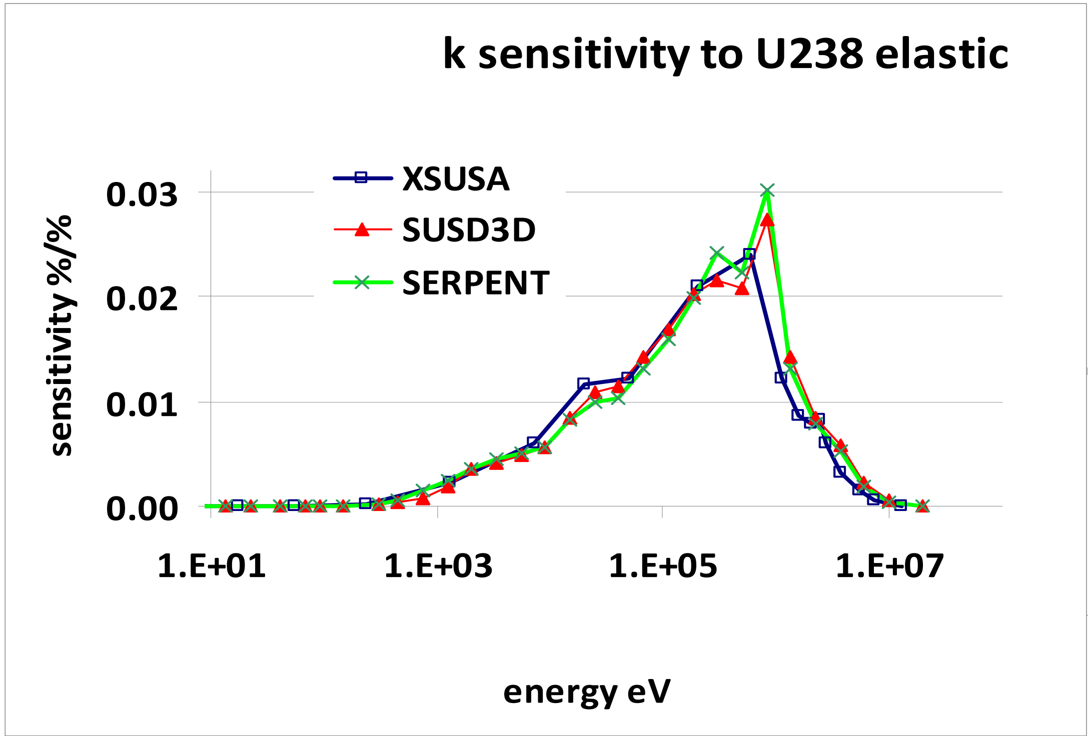


SNEAK-7A (SUSD3D – XSUSA - SERPENT)





SNEAK-7A (SUSD3D – XSUSA - SERPENT)



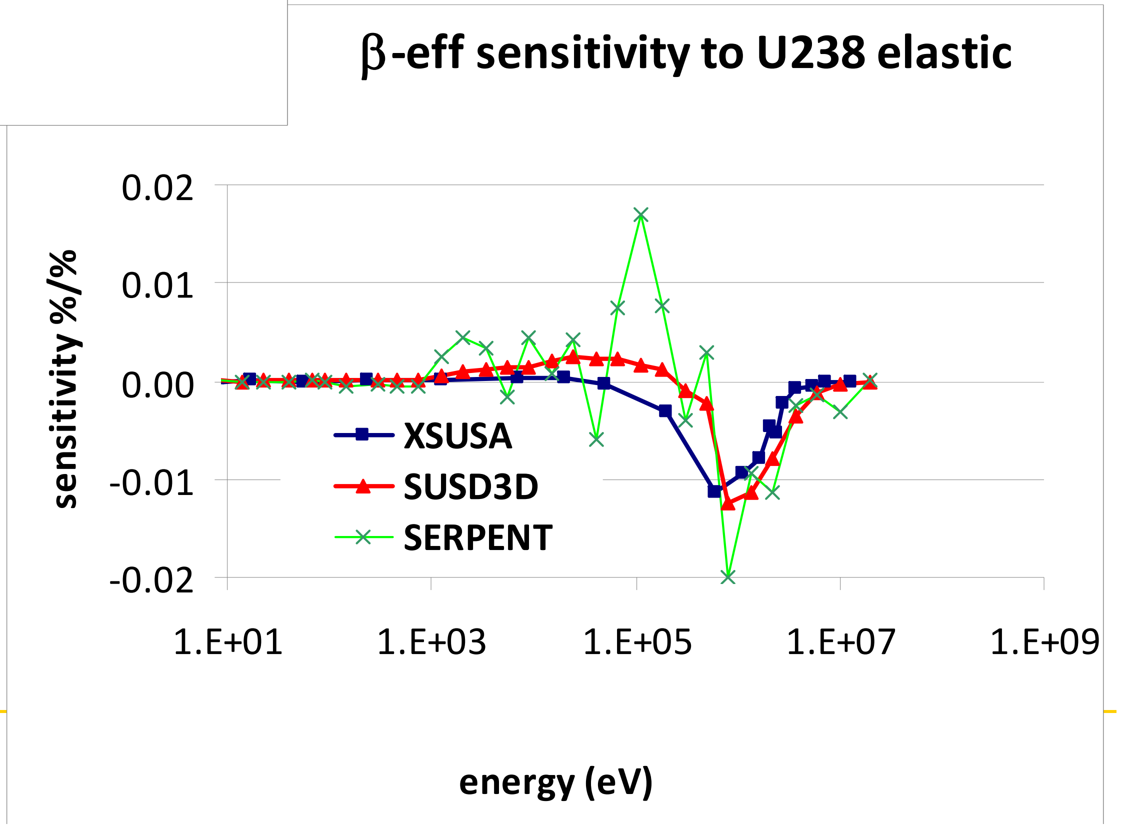


Table 7: Energy i

x	
^{239}Pu	σ_{ela}
^{239}Pu	σ_{inl}
^{239}Pu	σ_{fis}
^{239}Pu	$\bar{\nu}_{pro}$
^{239}Pu	$\bar{\nu}_{dela}$

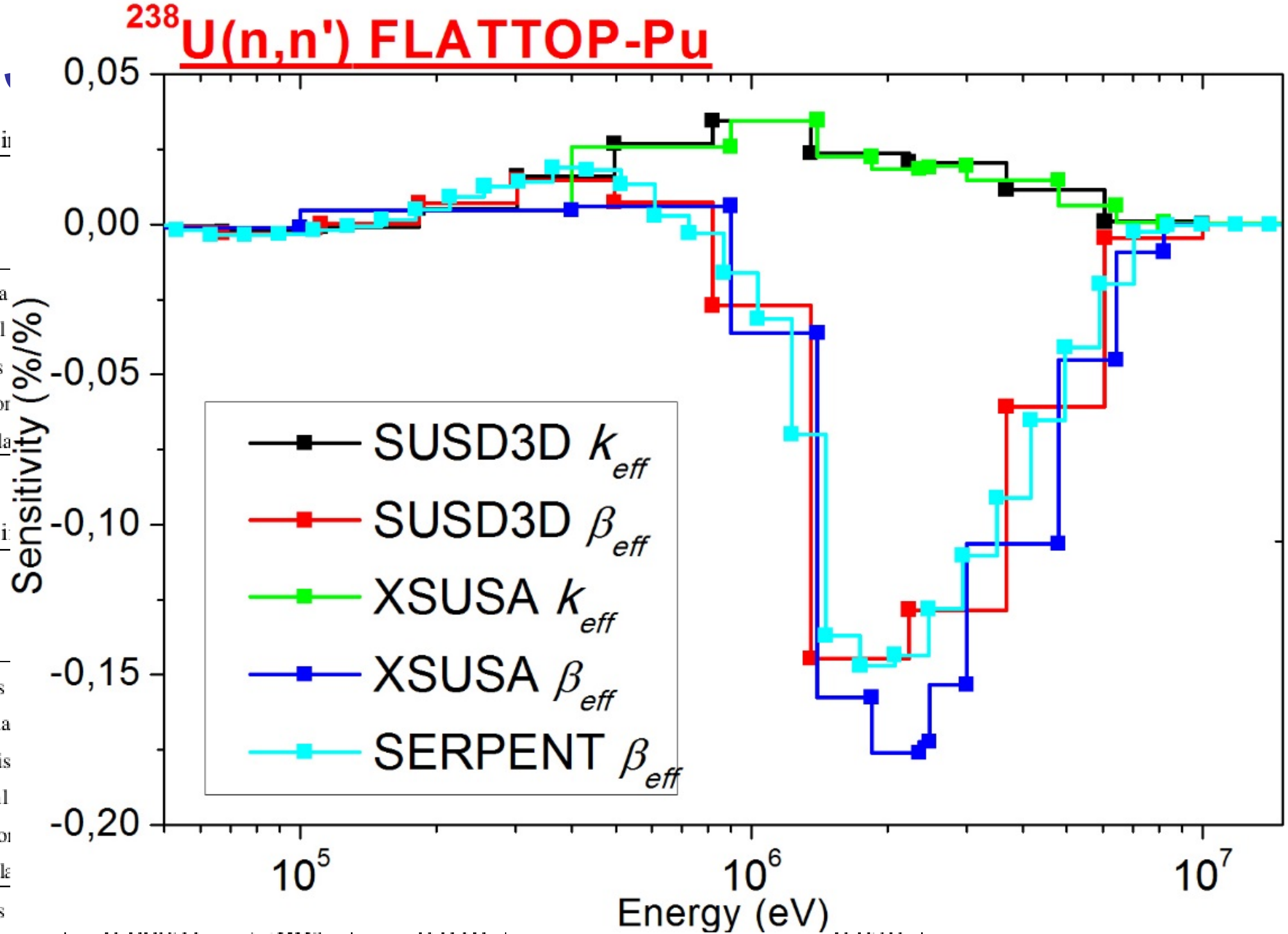


Table 8: Energy i

x					
^{238}U	σ_{fis}				
^{238}U	σ_{ela}				
^{238}U	σ_{dis}				
^{238}U	σ_{inl}				
^{238}U	$\bar{\nu}_{pro}$				
^{238}U	$\bar{\nu}_{del}$				
^{239}Pu	σ_{fis}				
^{239}Pu	σ_{ela}	-0.00821	± 30%	-0.010	-0.030
^{239}Pu	σ_{dis}	-0.01887	± 1.3%	-0.017	-
^{239}Pu	σ_{inl}	-0.03922	± 3.4%	-0.042	-0.046
^{239}Pu	$\bar{\nu}_{prompt}$	-0.85976	± 0.1%	-0.879	-0.918
^{239}Pu	$\bar{\nu}_{delayed}$	+0.58663	± 0.1%	+0.588	+0.561

CONCLUSIONS

- SNEAK-7A & 7B experiments were proposed for an inter-comparison exercise involving cross section sensitivity and uncertainty codes. Several solutions were received up to now using different, both deterministic and stochastic compute codes (SUSD3D, XSUSA, SERPENT, ERANOS, PARIS, TSUNAMI), different nuclear data libraries, energy group structures and modelisation of the geometry. Good consistency was observed between the sensitivities, both integral values and sensitivity profiles. Possible reasons for some discrepancies were identified (elastic sensitivities).
- **Solutions from other participants are most welcome.**

Sensitivity & uncertainty in β-eff

$$\beta_{eff} = 1 - \frac{k_p}{k}$$

Monte Carlo: M. M. Bretscher

Sensitivity of β-eff can be obtained as a (properly weighted) difference between two standard sensitivity terms:

$$\frac{\sigma}{\beta_{eff}} \frac{\partial \beta_{eff}}{\partial \sigma} = -\frac{\sigma}{\beta_{eff}} \frac{\partial \left(k_p / k \right)}{\partial \sigma} = \frac{k_p}{k - k_p} \left(S_k - S_{kp} \right)$$

or alternatively:

$$\boxed{\frac{\sigma}{\beta_{eff}} \frac{\partial \beta_{eff}}{\partial \sigma} = \frac{1 - \beta_{eff}}{\beta_{eff}} \left(S_k - S_{kp} \right)}$$