PROPAGATION OF NUCLEAR DATA UNCERTAINTIES FOR FUSION POWER MEASUREMENTS

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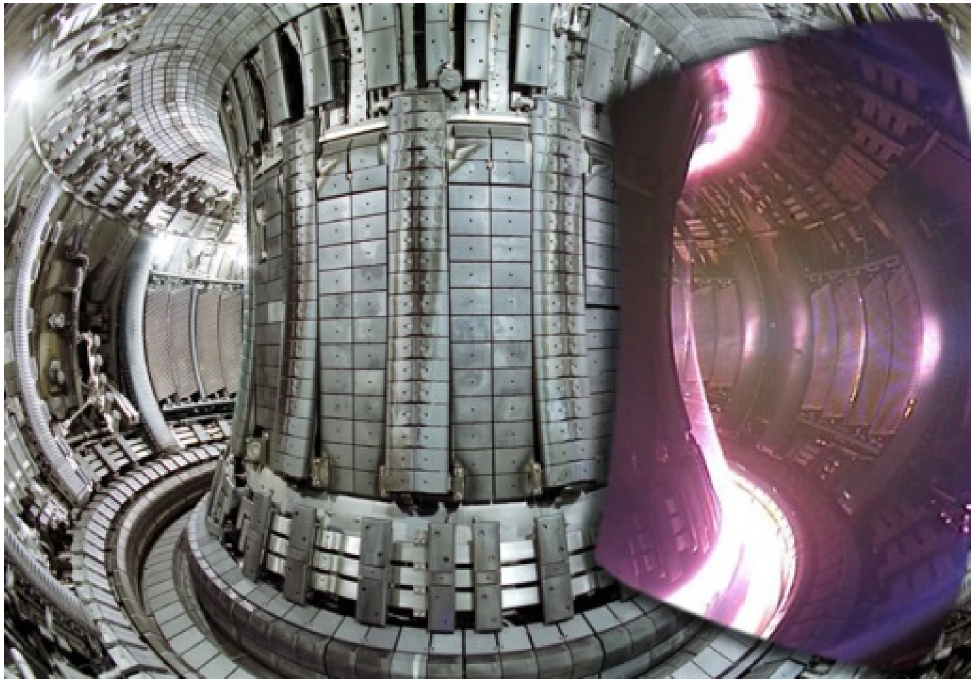
Fusion power measurements

- The fusion power is determined by measuring the neutron emission
  - Plasma performance
  - Regulatory demands
  - Ion densities and temperatures
  - Tritium accountancy
- High accuracy in the determination of the neutron emission essential
  - 2.5 MeV neutrons from dd-plasma.
  - 14 MeV neutrons from dt-plasmas.



Neutron measurements: neutron activation systems

- Neutron activation system reference for measurement of neutron emission @ JET and ITER
- Sample close to plasma → activated;
  - $^{115}In(n,n')^{115m}In$
  - $^{93}Nb(n,2n)^{92m}Nb$
- Activation + decay constant → integrated reaction rate
- + activation cross-section → local neutron flux
- + machine response (MCNP) → neutron emission → FUSION POWER

Neutron activation systems and nuclear data

$$R = \int \sigma_a(E)\Phi(E)\partial E$$

R is the activations rate

$\sigma_a(E)$, activation cross-section $\quad$ ${}^{115}In(n,n')^{115m}In$

$\Phi(E) = f(ND_T)$, neutron flux

ND_T transport nuclear data

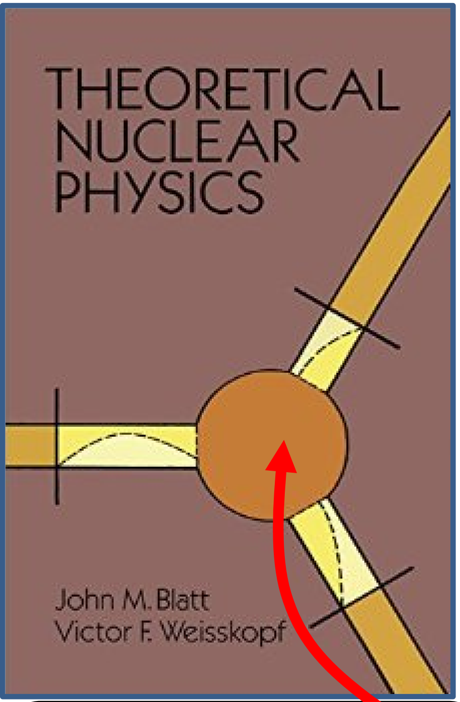
i.e.

Inferred fusion power $= f(\sigma_a(E), ND_T)$

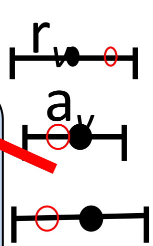
- We need to propagate the uncertainty of σ_a and ND_T to R.

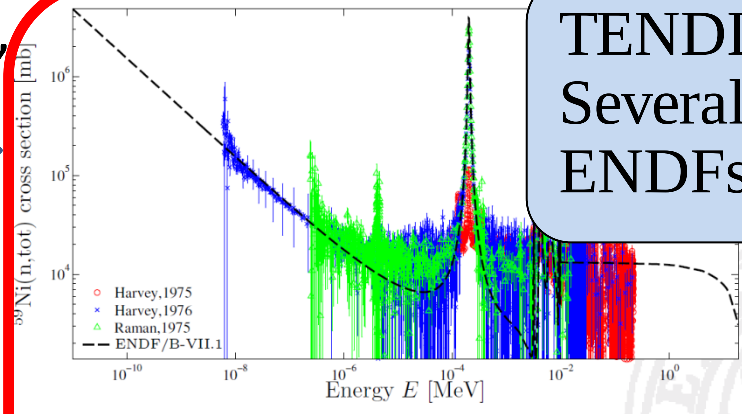
Total Monte Carlo: TMC

Nuclear model code, e.g., TALYS



Sampling model parameters

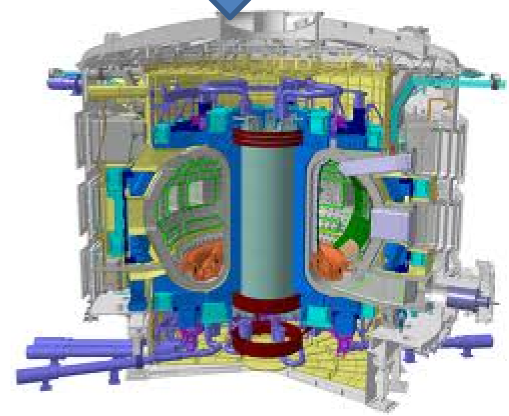




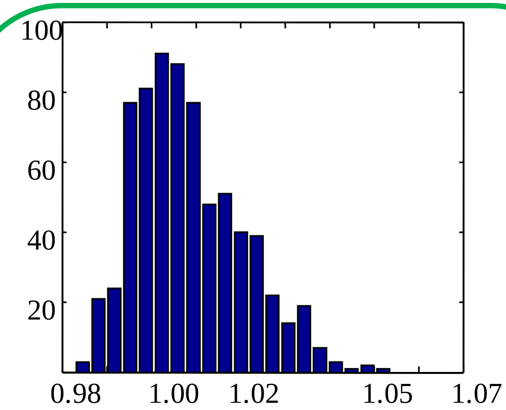
Calibration

TENDL: Several ENDFs

MCNP, SERPENT



Application

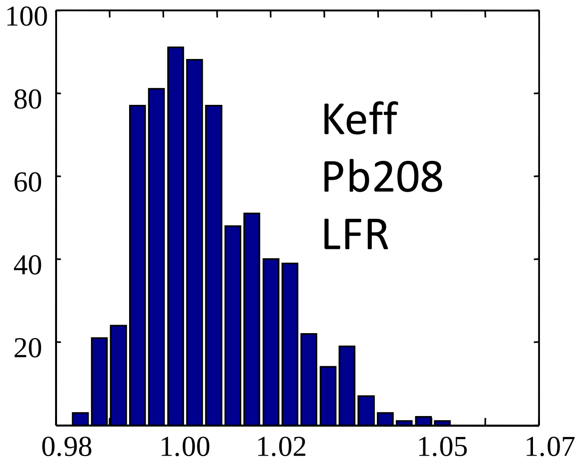


$$\sigma^2_{obs} = \sigma^2_{ND} + \sigma^2_{stat}$$

Results

TMC

- Straight forward and transparent treatment of the uncertainty propagation
- No linearization as used in perturbation methods.
- Non Gaussian behavior in input and output can be modelled.

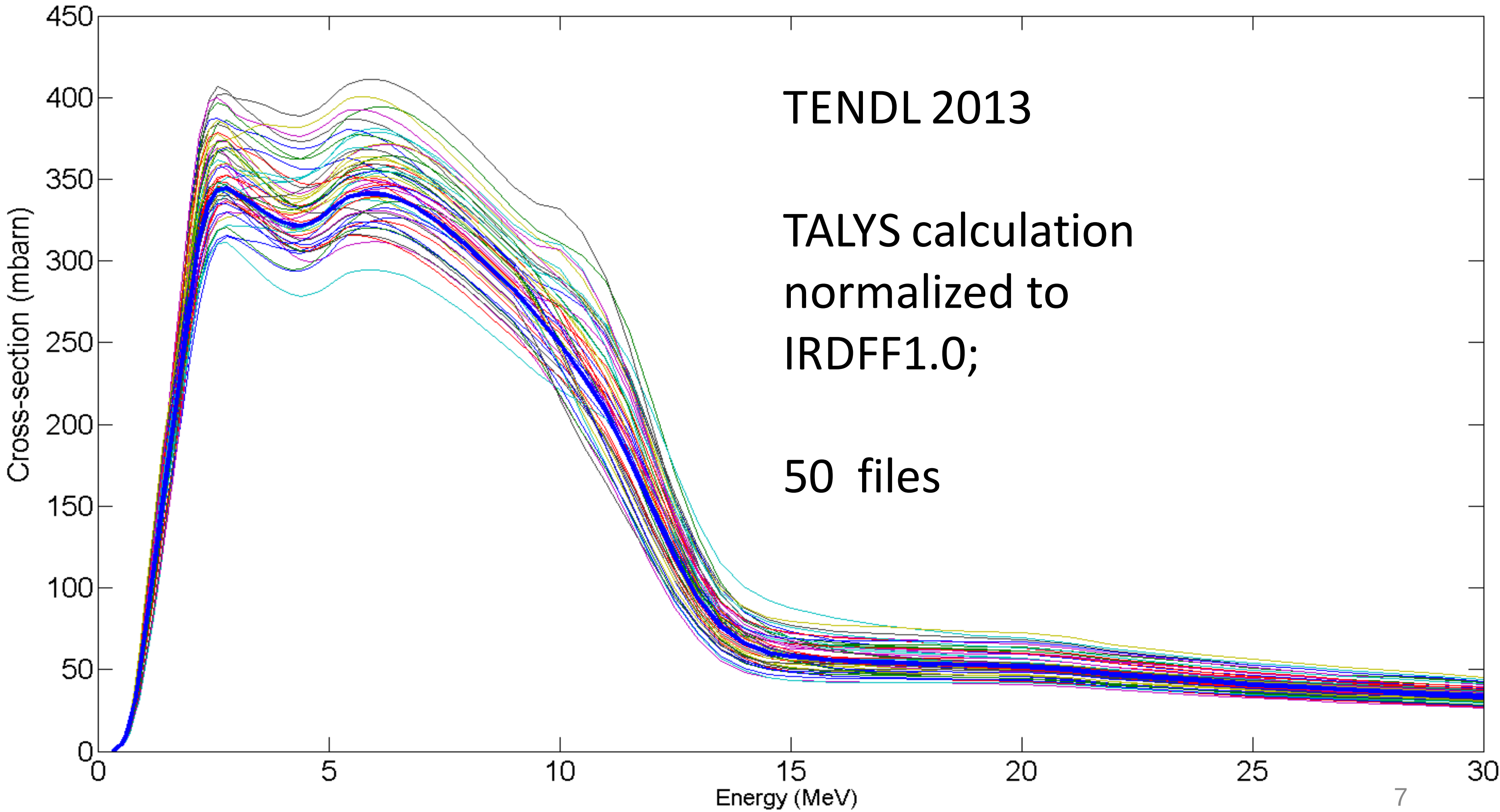


- More complete uncertainty quantification

  - angular distributions

  - cross correlation: e.g. cross sections / angular distributions

Example TMC for $^{115}In(n,n')In^{115m}$



TENDL 2013

TALYS calculation normalized to IRDFF1.0;

50 files

Results: $^{115}In(n,n')^{115m}In$ activation reaction

One group cross-section

$\propto$ Reaction rate

	This work TENDL2013 [mbarn]	Gediminas et al. IRDFF1.0	E.M. Zsolnay et al. IRDFFF1.0	
			Exp.	Calc.
^{252}Cf	190.5 (6.6±0.7 %)	190.6 (1.7 %)	197.4 (1.4 %)	190.6 (1.7 %)
JET DD	76.0 (7.4±0.7%)	76.1 (2.2 %)	-	
JET DT	37.4 (7.2±0.7 %)	37.5 (1.4 %)	-	

- TMC → high uncertainties, likely due to 'strong' E_n-E_n correlations.
- IRDFF1.0 small uncertainty (1.7%) comparing to C/E (3.6%).

G. Stankunas, P. Batistoni, S. Conroy, H.Sjöstrand, Nuclear Instruments and Methods in Physics Research Section A **788**, 168-172, (2015)

E.M. Zsolnay, R. Capote, H.J. Nolthenius, A. Trkov, Summary Description of the New International Reactor Dosimetric and Fusion File (IRDFF release 1.0), INDC(NDS)-0616

TENDL transition

- TENDL2013 qualitative comparisons to experimental data for determining ND-uncertainty bands

- TENDL2015 quantitative comparisons to experimental data based on a more consistent implementation of Bayes' theorem [1] [2]

[1] P. Helgesson, H .Sjöstrand et al., "Combining Total Monte Carlo and Unified Monte Carlo: Bayesian nuclear data uncertainty quantification from auto-generated experimental covariances", Progress in Nuclear Energy, under review (2016)
[2] A.J. Koning, Bayesian Monte Carlo method for nuclear data evaluation The European Physical Journal A 51 (12), 1-16, 2015

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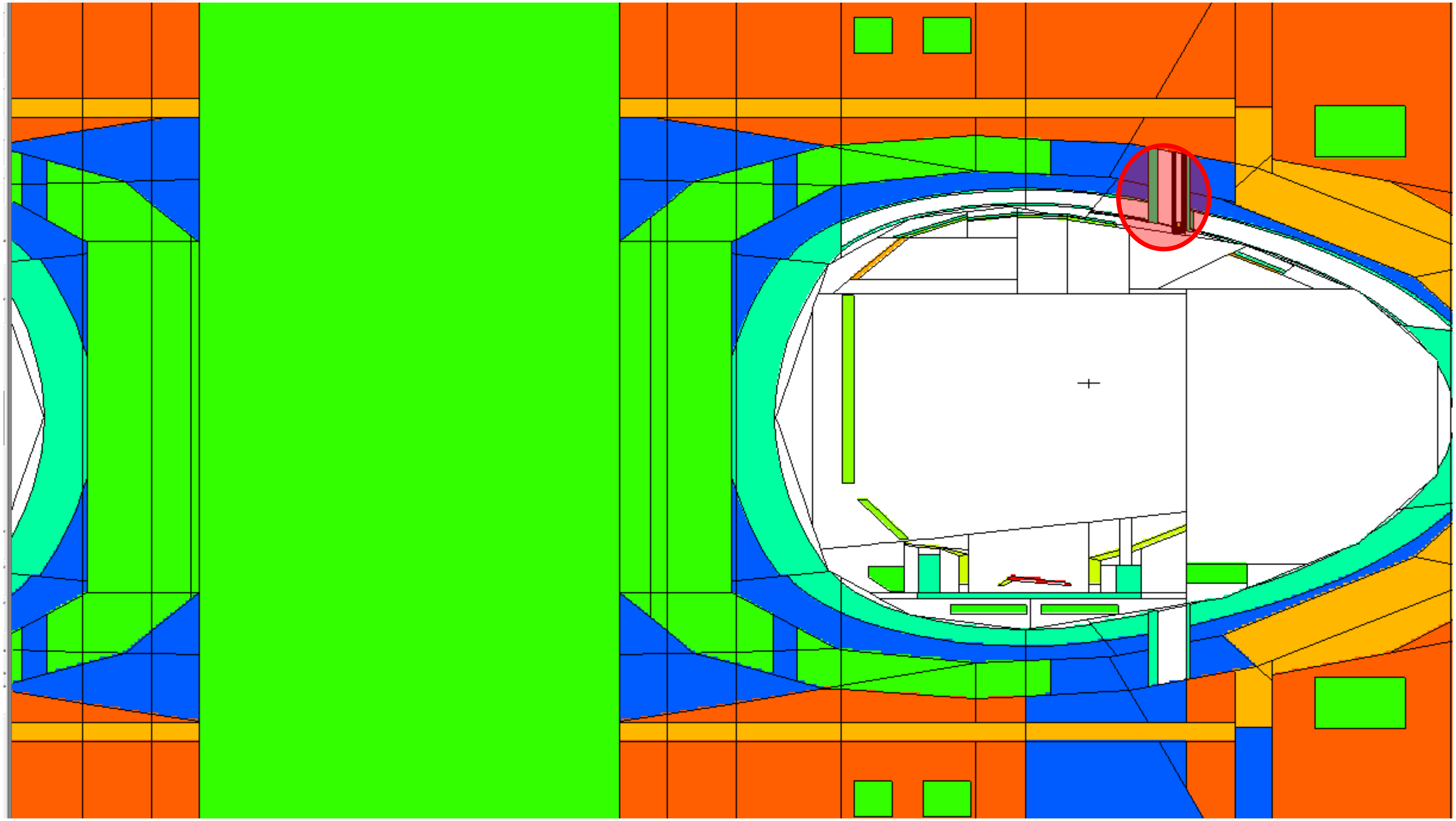
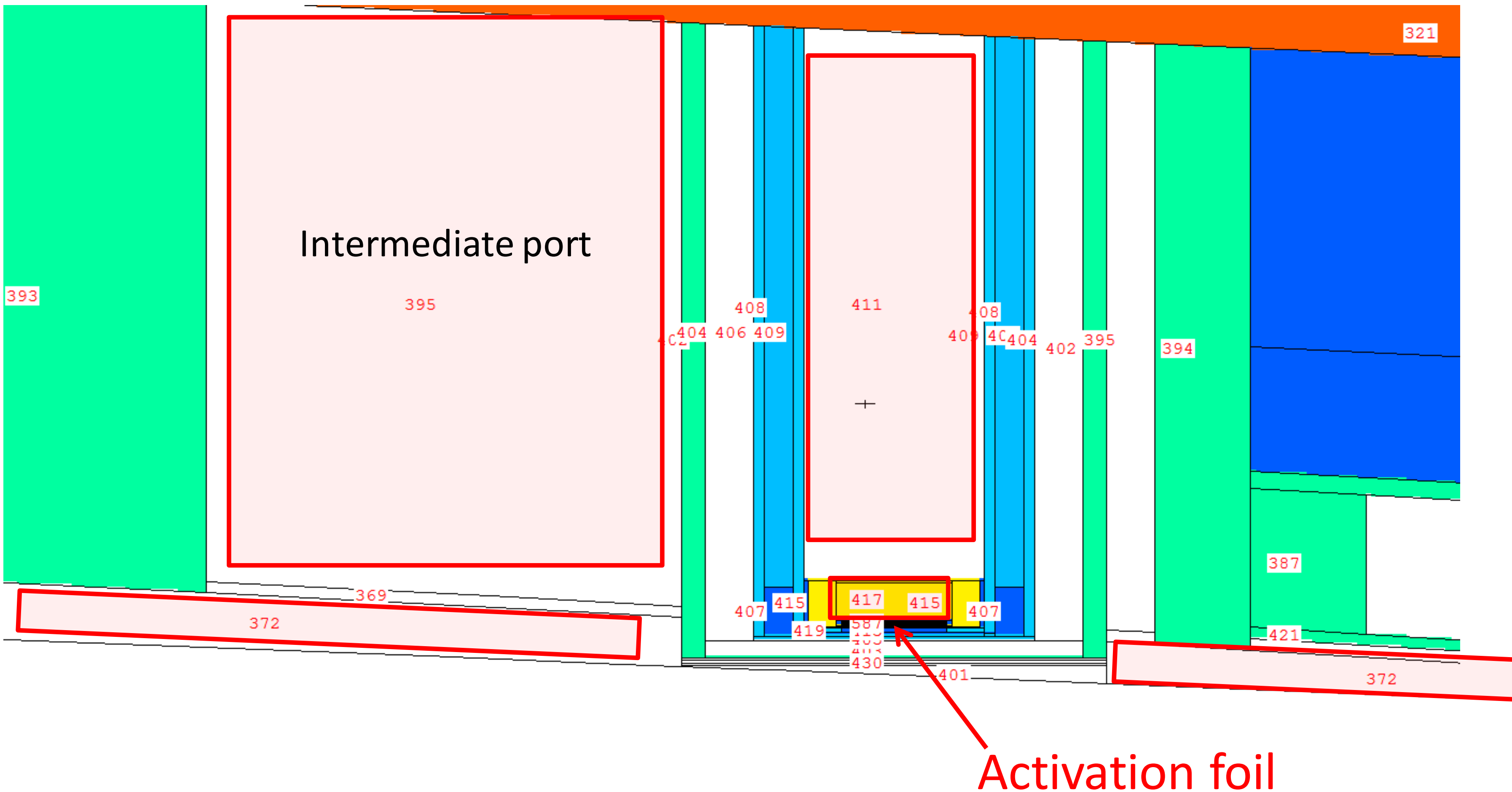
TMC for transport uncertainties

- ^{52}Cr, ^{54,56}Fe, ^{58,60}Ni, and ^{63,65}Cu, considered to have the largest impact
- TENDL 2015 random files processed to ACE format
- MCNP6 (~300 random files /isotope)
  - transport uncertainty in the reaction rate
    - $^{115}In(n,n')^{115m}In$ (DD and DT)
    - $^{93}Nb(n,2n)^{92m}Nb$ (DT)
- Results compared to FENDL 2.1

JET MCNP model

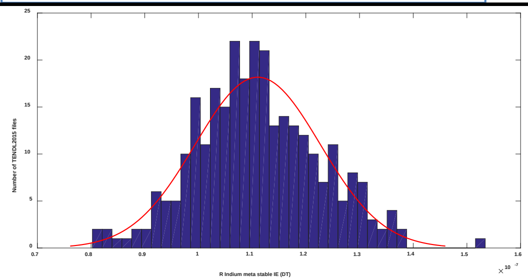


MCNP model zoom in around activation foil.



Results for ΔND_t TENDL2015

Typically Gaussian "uncertainties"

	FENDL vs. TENDL (%)	STD ND (%)	Δ (STD ND) (%)
DD - below - R (^{115}In)	1.8	0.8	0.04
DD - above - R (^{115}In)	3.2	1.7	0.1
DT - below - R (^{115}In)	4.4	3.8	0.2
DT - above - R (^{115}In)	3.7	4.5	0.2
DT - below - R (^{93}Nb)	0.9	1.1	0.05
DT - above - R (^{93}Nb)	2.1	2.2	0.1
DT - below - photon	-	3.8	0.2
DT - above - photon	-	3.4	0.2

Conclusion

The TMC method has been used to:

propagated uncertainty in the activation reaction $^{115}In(n,n')^{115m}In$
- DD and DT, TENDL2013; 7 % uncertainty (probably an over estimation)
- IRDFF1.0 (DD); 2 % (might be an under estimation).

calculatate reaction rate uncertainty due to uncertainty in the nuclear data of the JET machine:
- DD: 1 - 2 %
- DT: 4 %, ^{115}*In, 0.3 MeV Th.*
- DT: 1 – 2 %, ^{93}*Nb, 8 MeV Th.*

Choice of activation foil is important!

- TENDL2015 comprehensive covariance information; improvements possible. The effort to improve the TENDL covariance information, can increase or decrease the final uncertainty estimates.

THANK YOU FOR LISTENING

Acknowledgment
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Questions?

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Choice of activation foil is important!

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