NEURAL NETWORK MODEL

PERFORMANCE ANALYSIS

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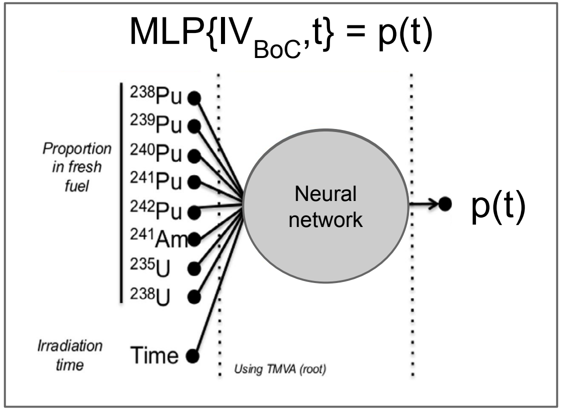
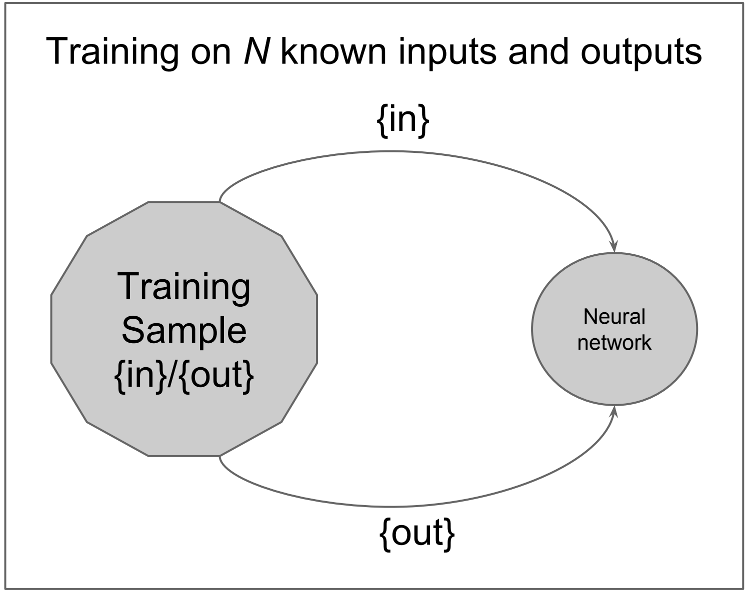
TECHNICAL WORKSHOP ON FUEL CYCLE SIMULATION
2017/07

Principle

- Prediction of neutronics metrics evolution during irradiation:
  - Cross section *(fission, capture (n,2n))*
  - Neutron multiplication factor





Building Upon Contribution from CLASS Community

PWR:

- MOX-Pu

B. Leniau, et al., "A neural network approach for burn-up calculation and its application to the dynamic fuel cycle code CLASS," Annals of Nuclear Energy, 81, (2015).

- MOX-Pu/Am

A.-A. Zakari-Issoufou, et al., "Americium mono-recycling in PWR: A step towards transmutation" Annals of Nuclear Energy, 102, (2016).

- MOX-Pu/LEU

F. Courtin, et al., "Neutronic predictors for PWR fuelled with multi-recycled plutonium and applications with the fuel cycle simulation tool CLASS" Progress in Nuclear Energy, 100, (2017)

SFR

- MOX-Pu

B. Leniau, et al., "Generation of FBR-Na physics models for the nuclear fuel cycle code CLASS", PHYSOR 2016, USA

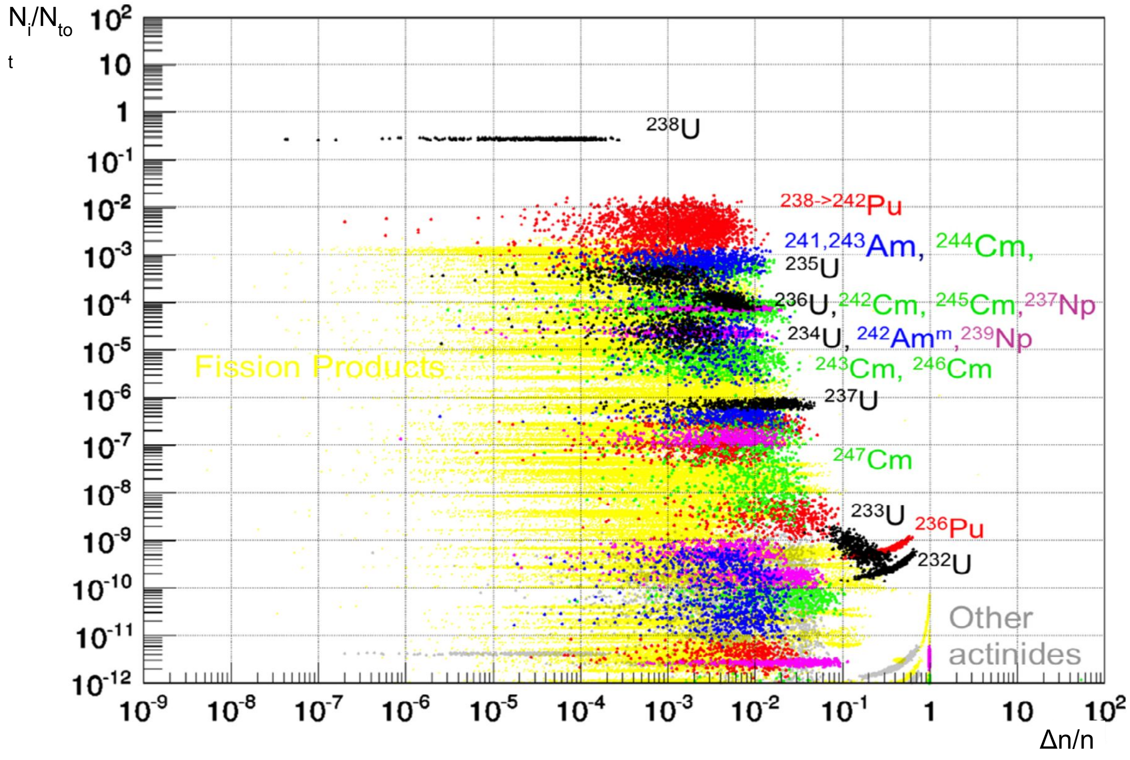
Depletion with predicted cross sections

Predicted cross sections:
- fission
- capture
- (n,2n)

reference: MURE (all reactions)

From B. Leniau, et al., "A neural network approach for burn-up calculation and its application to the dynamic fuel cycle code CLASS," Annals of Nuclear Energy, 81, (2015).

Relative differences on EoF composition computed using JEFF-3.1.1 and predicted cross sections



MOX - TRU

MOX-TRU required for some Fuel cycle study with CYCLUS (see Model vs Recipe presentation):

- Training depletions calculations: N=10, 100, 1000, 5000, 10000,
- Assembly calculation: 1/10 of an assembly with mirror boundary condition[1],
- Depletion tool: MURE,
- Data base: JEFF 3.1.1,
- Initial composition sampled on a Latin Hypercube, 239Pu as filler

Param	235U	TRU frac	Pu236	238Pu	240Pu	241(Pu+Am)	241Pu/ 241(Pu+Am)	242Pu	237Np	242Am*	243Am	242Cm	243Cm	244Cm	245Cm	246Cm
min	0	0.03	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
max	0.02	0.2	0.01	0.02	0.2	0.04	1	0.01	0.06	0.001	0.001	0.001	0.001	0.001	0.001	0.001

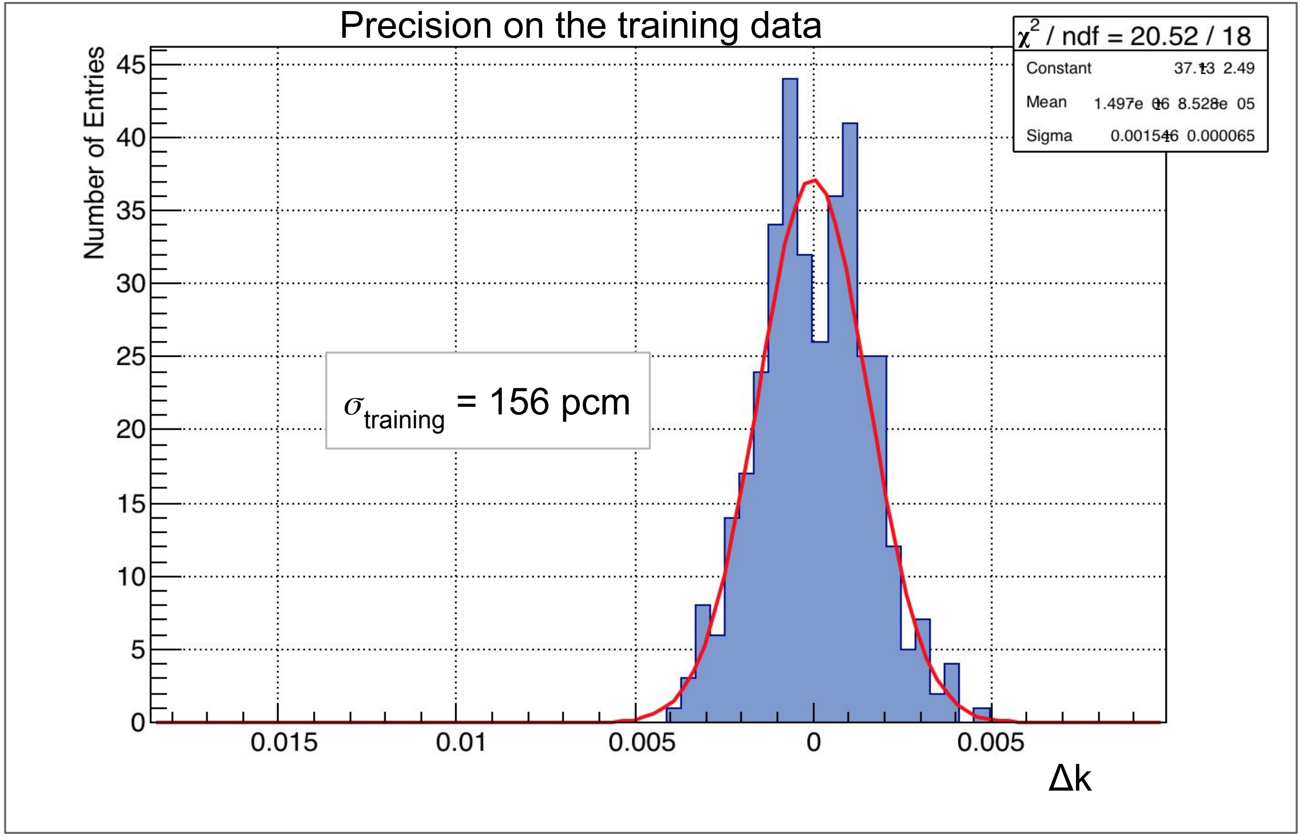
- Neural Network : TMVA [2]
- Hidden layer : 18,21,9
- Regression: Broyden-Fletcher-Goldfarb-Shannon method (back propagation). [2]
- Testing: 1000 depletion calculations inside sample space & 500 depletion calculations outside.

[1] N. Thiolliere, private communication. Subatch (2017).
[2] Hoecker, A., Speckmayer, P., Stelzer, J., Therhaag, J., von Toerne, E., Voss, H., 2007. TMVA: Toolkit for Multivariate Data Analysis, PoS ACAT, p. 040.

Overtraining: N=10

σ_{MCNP} = 120 pcm

$\sigma_{training}$ = 156 pcm



Measure of the σ on 1000 independent simulations

$<\sigma_{real}>$ = 11576 pcm

Training sample density

Precision improve with the density!

Reach the precision of the MC:

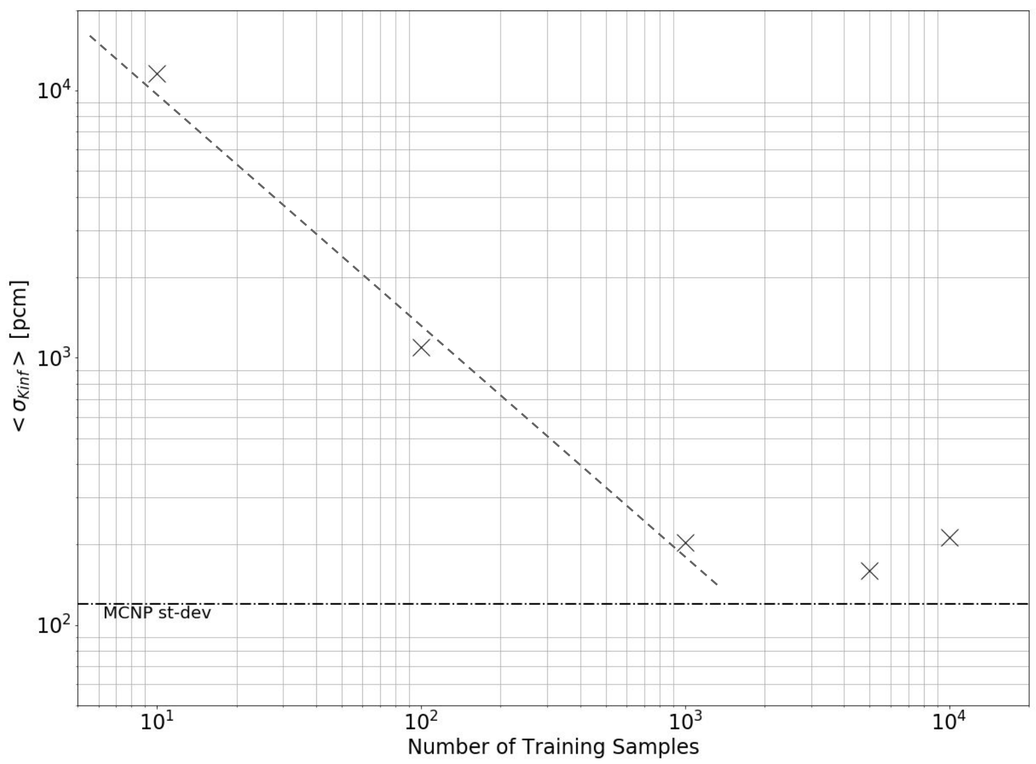
σ_{MCNP} = 120 pcm

1000-2000 samples probably enough !

Prob. with the 10 000 samples:

- Not enough training cycles !?
- Decrease of the NN quality ?

Evaluation of the prediction on 1000 independent calculations



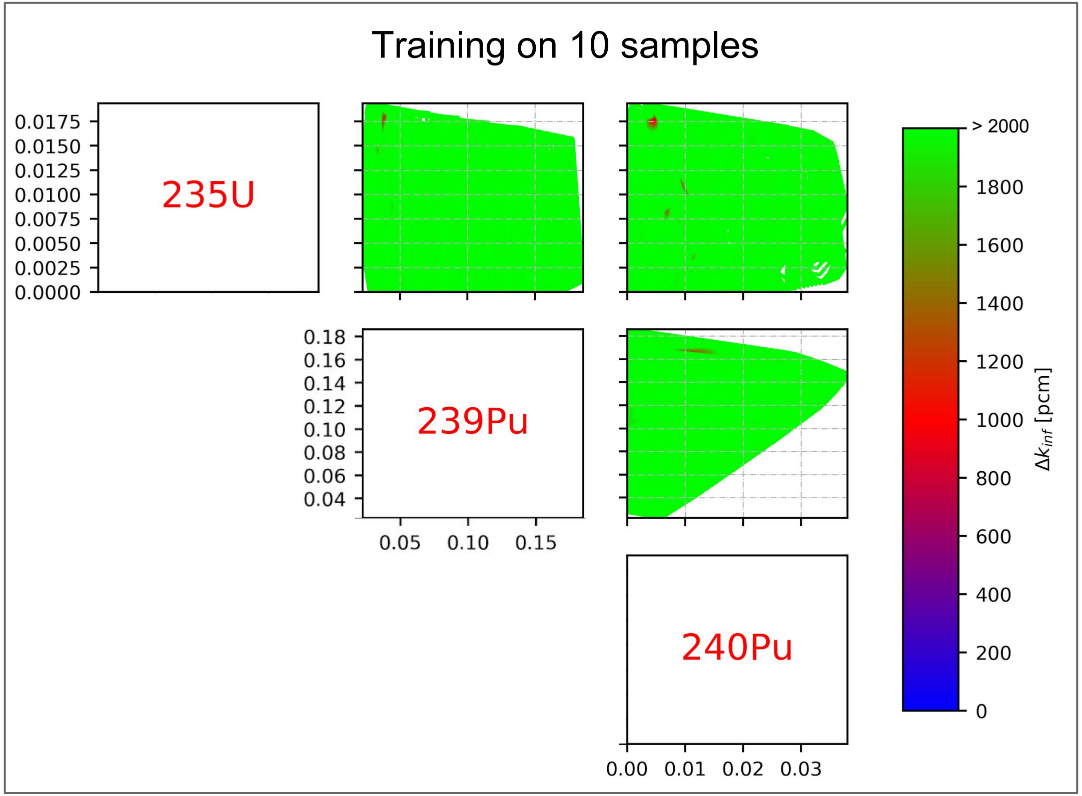
Precision Map: N=10, “inside” test data

Precision improve with the density

Reach the precision of the MC:

σ_{MCNP} = 120 pcm

Precision:
- 10 : σ > 1200 pcm | <σ> = 11e3 pcm



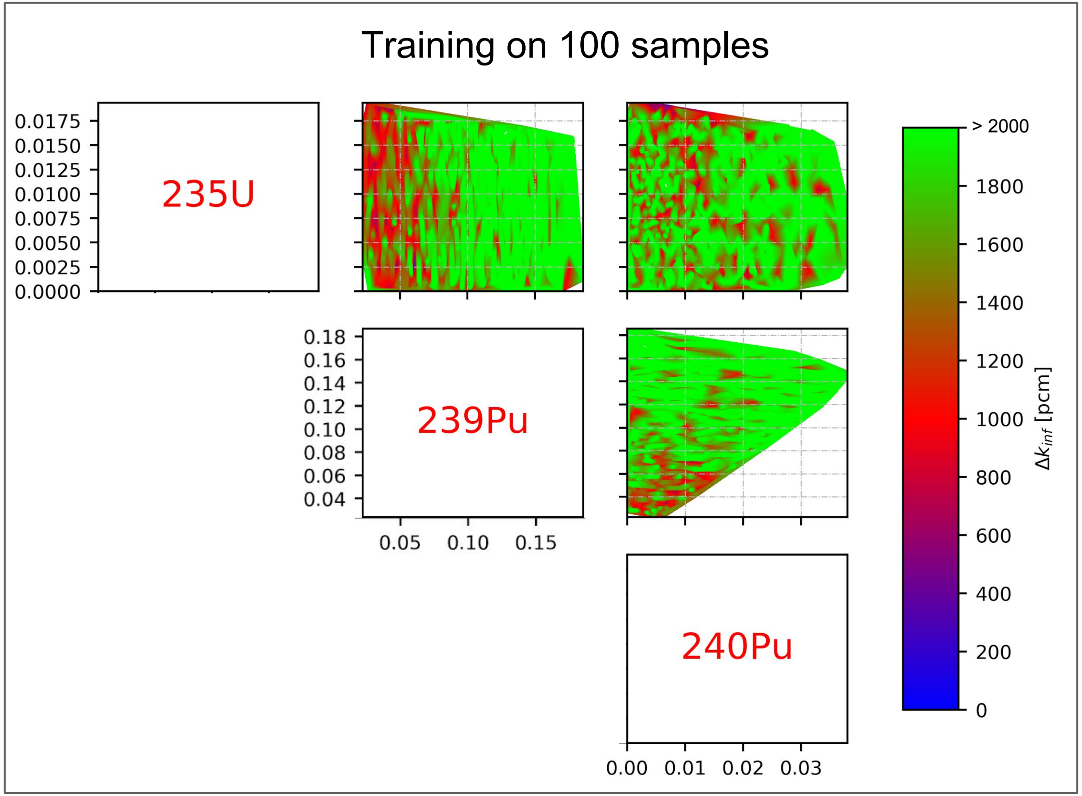
Precision Map: N=100, “inside” test data

Precision improve with the density

Reach the precision of the MC:

σ_{MCNP} = 120 pcm

Precision:
- 10 : σ > 1200 pcm | <σ> = 11e3 pcm
- 100 : σ > 800 pcm | <σ> = 1e3 pcm



Precision Map: N=1000, “inside” test data

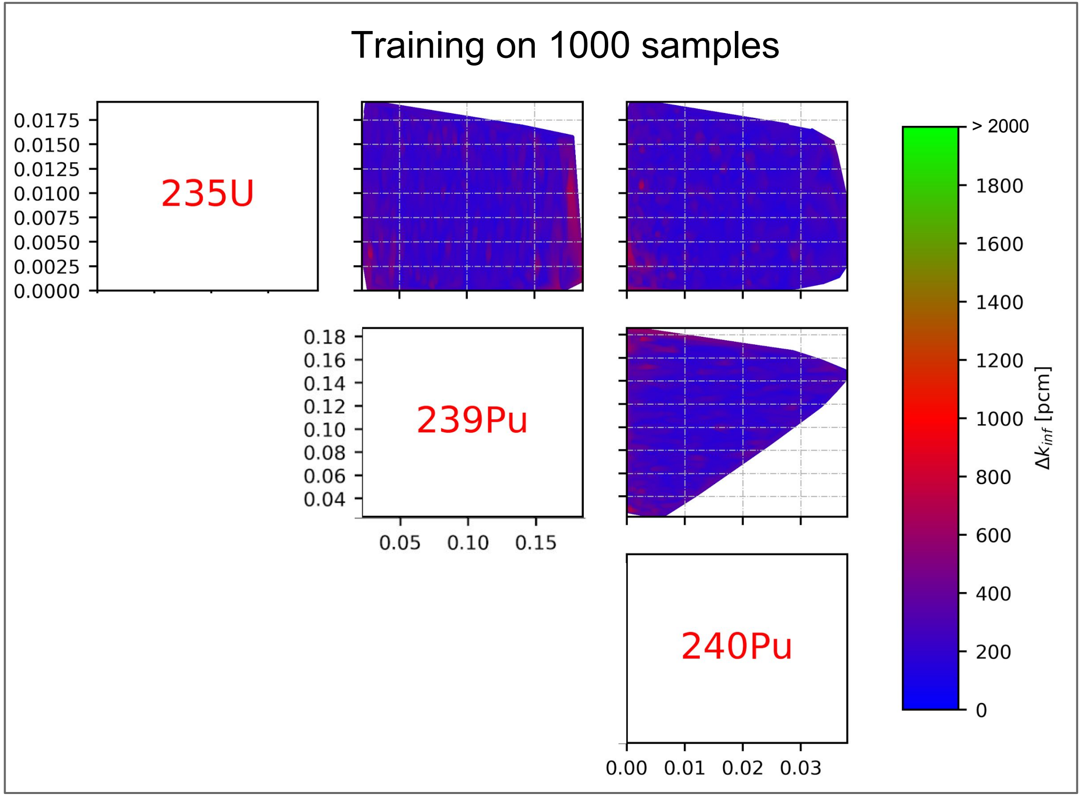
Precision improve with the density

Reach the precision of the MC:

σ_{MCNP} = 120 pcm

Precision:

- 10 : σ > 1200 pcm | $\langle\sigma\rangle$ = 11e3 pcm
- 100 : σ > 800 pcm | $\langle\sigma\rangle$ = 1e3 pcm
- 1000: σ < 800 pcm | $\langle\sigma\rangle$ = 200 pcm



Precision Map: N=5000, “inside” test data

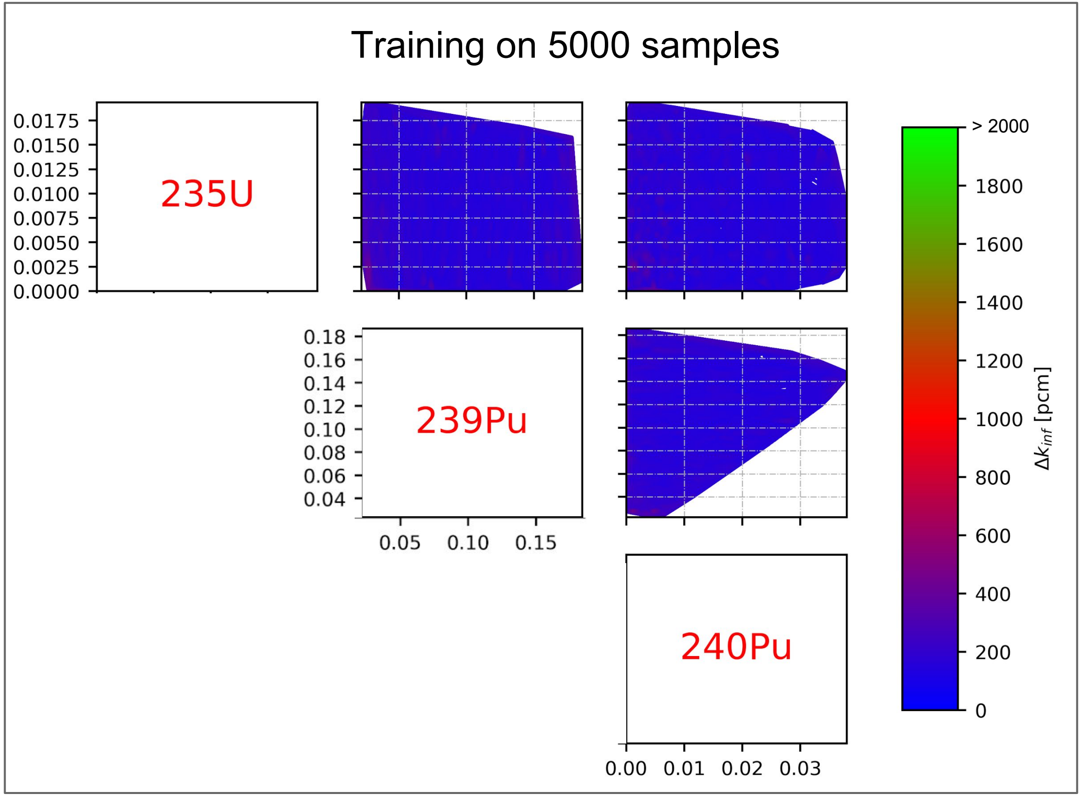
Precision improve with the density

Reach the precision of the MC:

σ_{MCNP} = 120 pcm

Precision:

- 10 : σ > 1200 pcm | <σ> = 11e3 pcm
- 100 : σ > 800 pcm | <σ> = 1e3 pcm
- 1000: σ < 800 pcm | <σ> = 200 pcm
- 5000: σ < 300 pcm | <σ> = 160 pcm



Precision Map: N=5000, “outside” test data

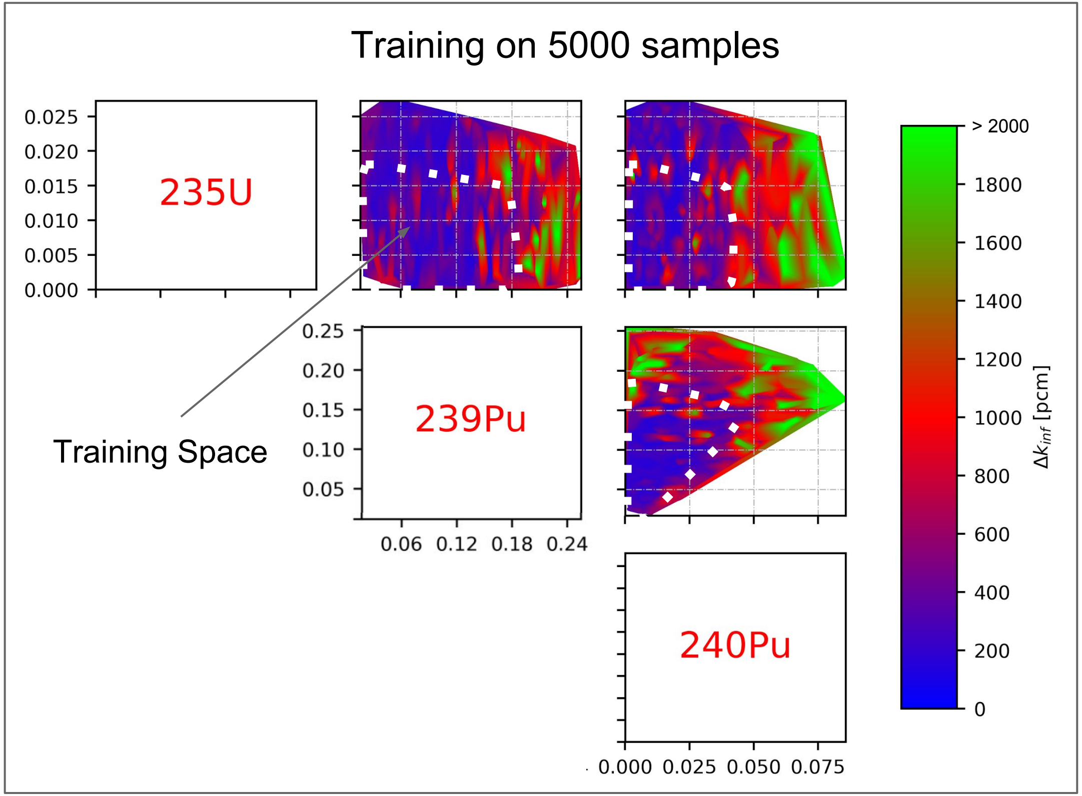
Precision improve with the density

Reach the precision of the MC:

σ_{MCNP} = 120 pcm

Precision:
- 10 : σ > 1200 pcm | <σ> = 11e3 pcm
- 100 : σ > 800 pcm | <σ> = 1e3 pcm
- 1000: σ < 800 pcm | <σ> = 200 pcm

σ grows outside of the training space !



Predicting other metrics:

- Prediction of neutronics metrics evolution during irradiation:
  - Cross section
  - Neutron multiplication factor

- Extension to fuel composition ?

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Neural Network train on 5000 training sample, without topology optimisation

Prediction of the 239Pu content with a non optimised:

$\boxed{\sigma = 4.2e\text{-}3}$

Direct prediction of the composition !?