Application of an Advanced Variance Reduction Technique for Bulk Shield Calculations of the IFMIF-DONES facility

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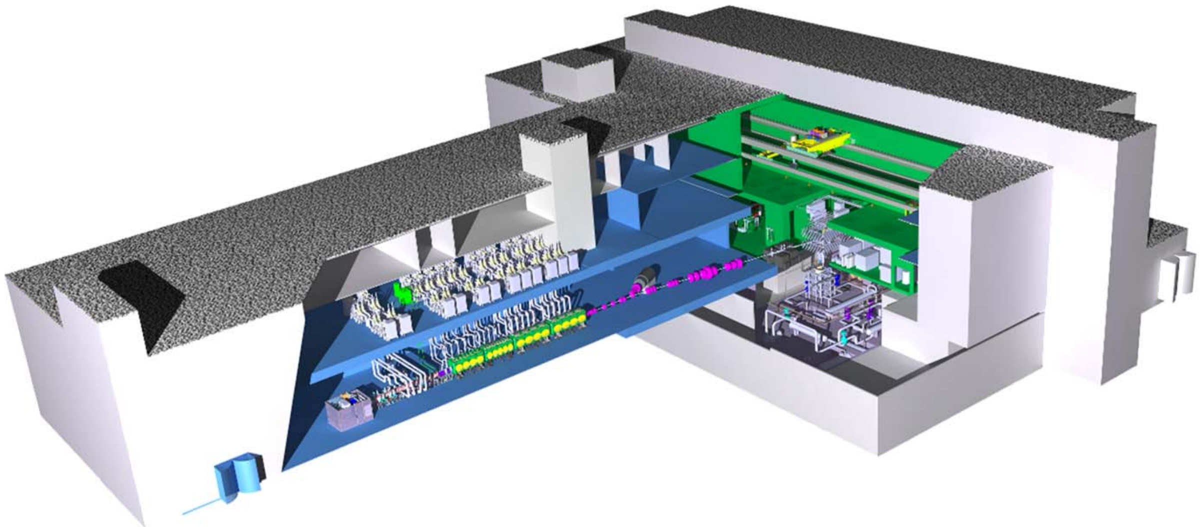
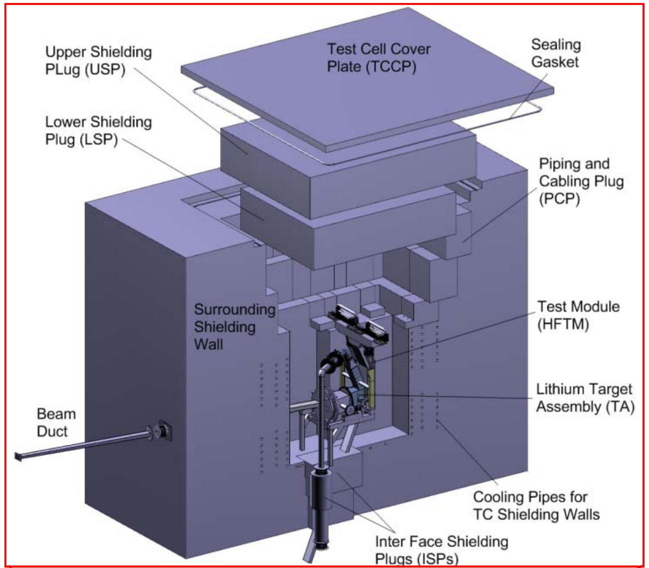


Outline

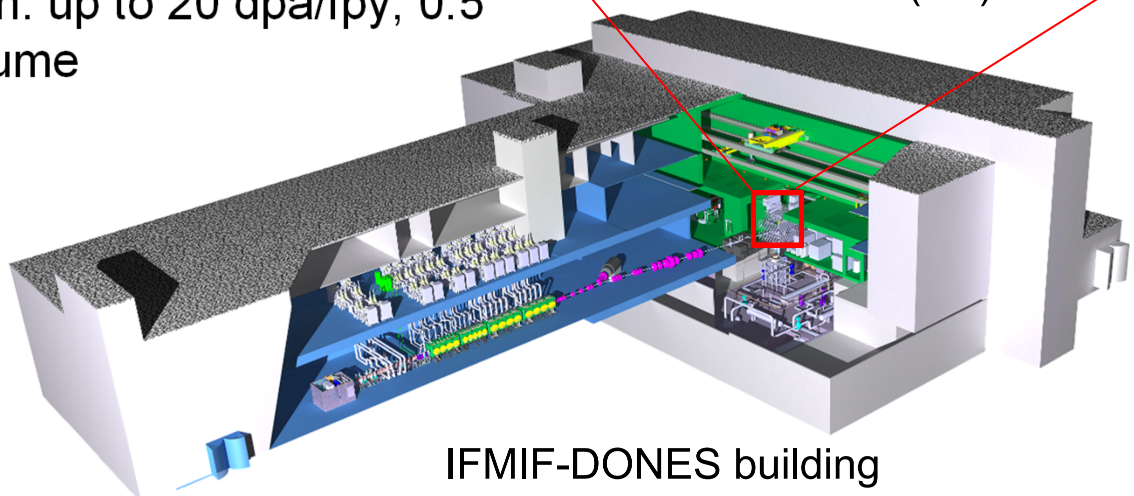
- Introduction
- Assessment of ADVANTG for IFMIF-DONES
- Improvements: methods and codes
- Summary and outlook

Introduction

- IFMIF-DONES
  - IFMIF: the International Fusion Materials Irradiation Facility
  - DONES: DEMO Oriented Neutron Source (downgraded, early neutron source)
  - Deuterium-Lithium neutron source
  - Deuteron beam: 1 x 40 MeV, 125 mA
  - Neutron: up to 55 MeV, 10^{15} n/cm^2/s
  - Material irradiation: up to 20 dpa/fpy, 0.5 Liter high flux volume



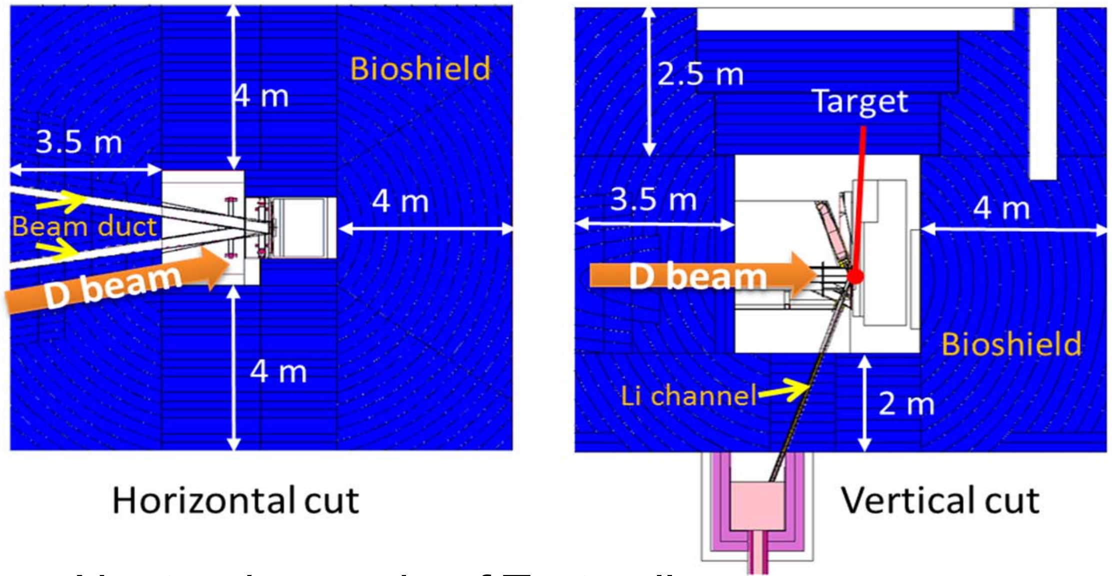
Test cell (TC)



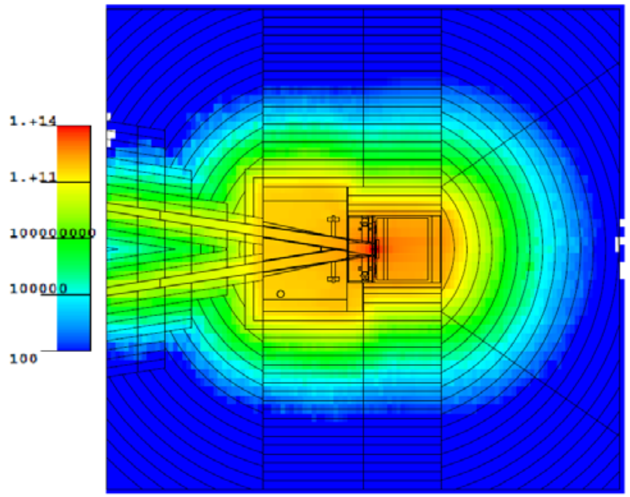
IFMIF-DONES building

Introduction

- Test cell shielding
  - Heavy concrete up to 4 m in thickness
  - Neutron flux varies >10^{10} n/cm^2/s
  - Bulk shielding with penetrations
  - Challenging for both Monte Carlo (MC) and deterministic simulation method.



Neutronics mode of Test cell



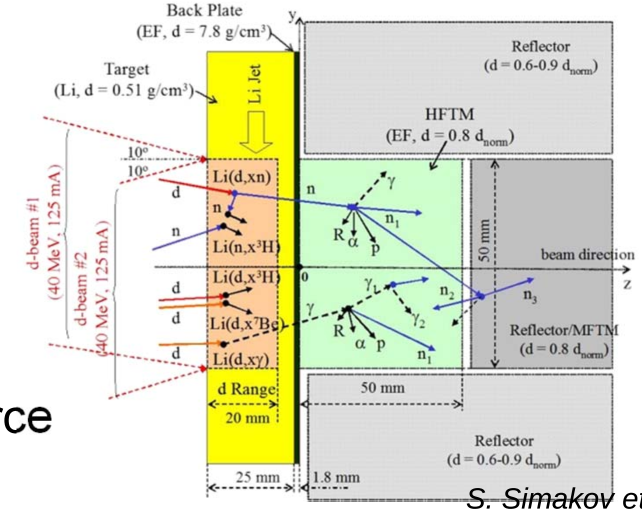
Neutron flux (n/cm^2/s)

Introduction

- Monte Carlo (MC) method
  - Common method for IFMIF-DONES shielding calculation
  - MCNP code, e.g. MCNP5-1.6
  - Variance reduction technique required for bulk shielding, e.g. superimposed weight-window (WW) mesh
- ADVANTG
  - A tool for automatic generation of MCNP weight-window mesh for variance reduction.
  - Version 3.0.3
- Is ADVANTG suitable for IFMIF-DONES ?
  - MCNP source subroutine used instead of SDEF card
  - Penetration in the bulk shielding
  - …

Assessment of ADVANTG for IFMIF-DONES

- McDeLicious
  - A MCNP source subroutine
  - Simulate the generation of source neutrons/photons from deuterium-lithium reactions
  - Normalized by deuteron: 1 d -> 1n, the source neutron weight varies as neutron yields
  - Well validated against experiments, reference code for IFMIF-DONES
- Issue
  - ADVANTG code require a SDEF source in the MCNP input file
- Solution
  - Create a approximation



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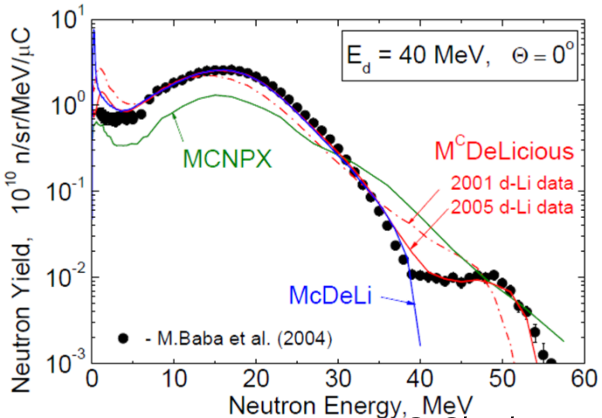
Ed = 40 MeV
Exp.: M. Hagiwara et al.



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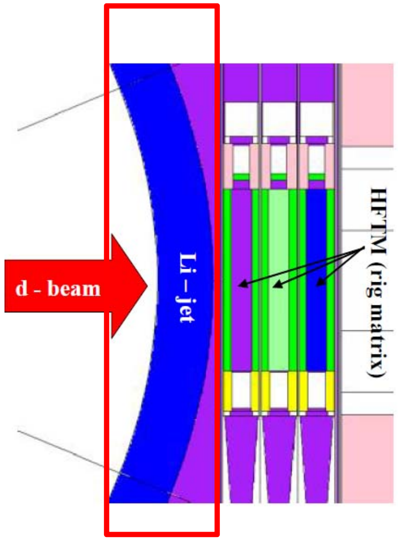
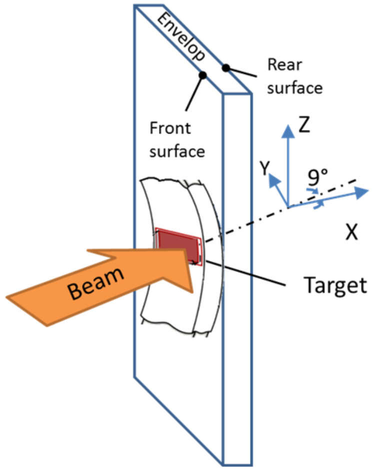
Assessment of ADVANTG for IFMIF-DONES

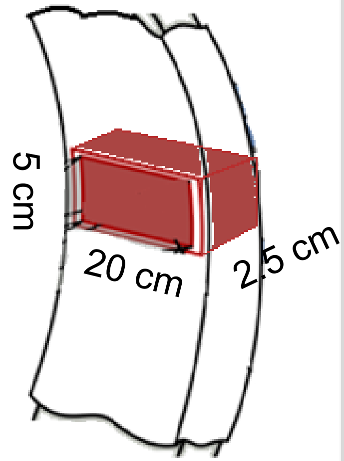
- SDEF source
  - Tally source neutron in a quasi-infinite slab
  - Neutron spectrum, angular spectrum, neutron weight
  - Create a SDEF source in a box region.



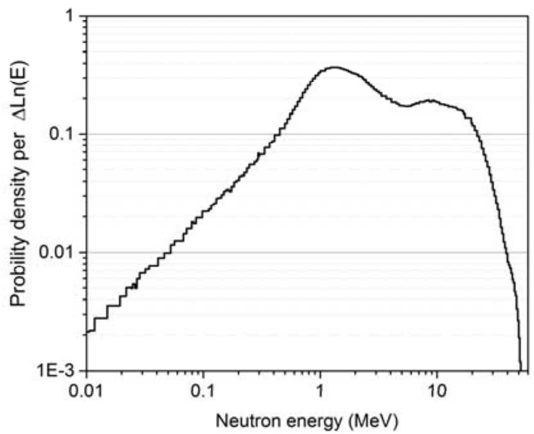
Lithium target



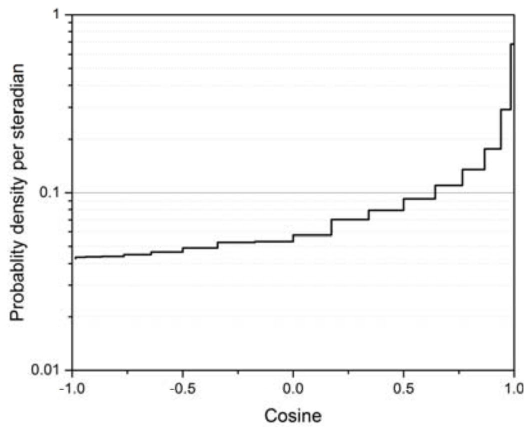
quasi-infinite slab



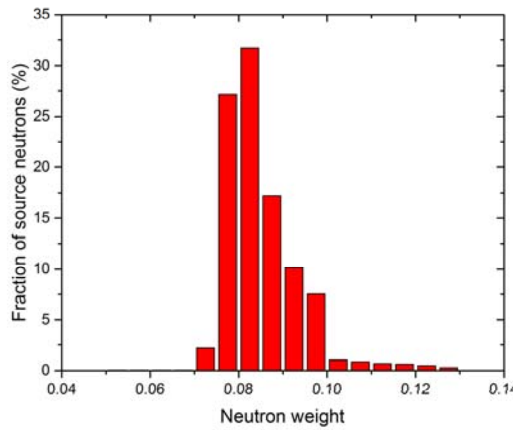
SDEF source



Neutron spectrum



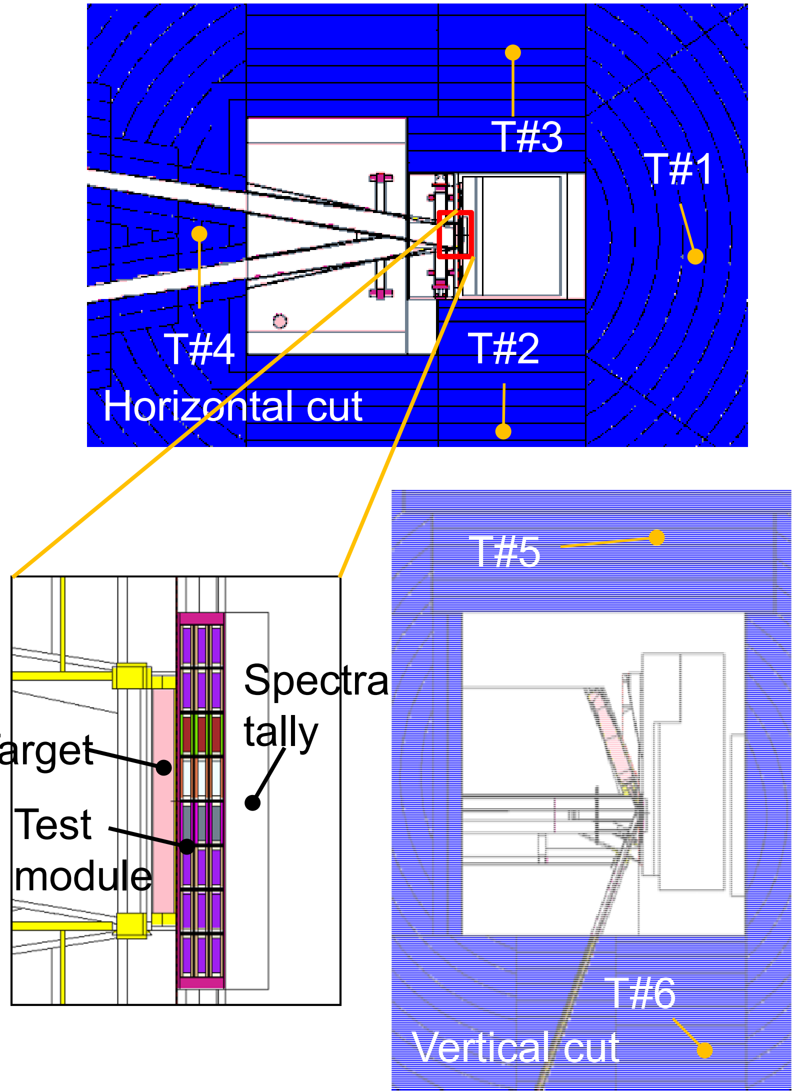
Neutron angular distribution



Neutron weight distribution

Assessment of ADVANTG for IFMIF-DONES

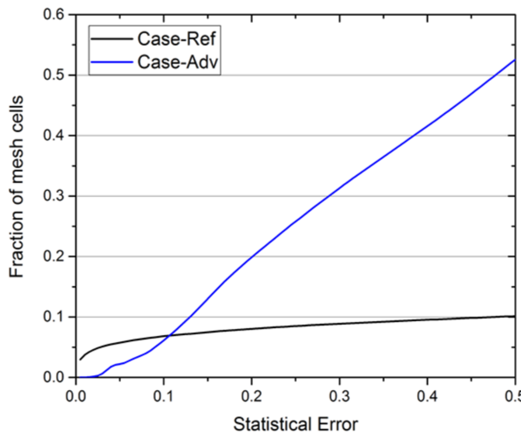
- Normal MCNP run (Case-Ref)
  - MCNP5.1.6, FENDL3 release 4;
  - Without WW, as reference
  - 10^8 neutron histories, mode n
  - Mesh tally covering the whole TC
  - Additional cell tally (T#), spectrum tally
- ADVANTG WW (Case-Adv)
  - Mesh: 120 × 80 × 125 intervals in X, Y and Z direction, fine 10 × 3 × 2 cm, coarse 20 × 20 × 20 cm
  - Library: 27n19g
  - Method: FW-CADIS, global weighting treatment
  - Pn order: 5
  - Source biasing turned off!

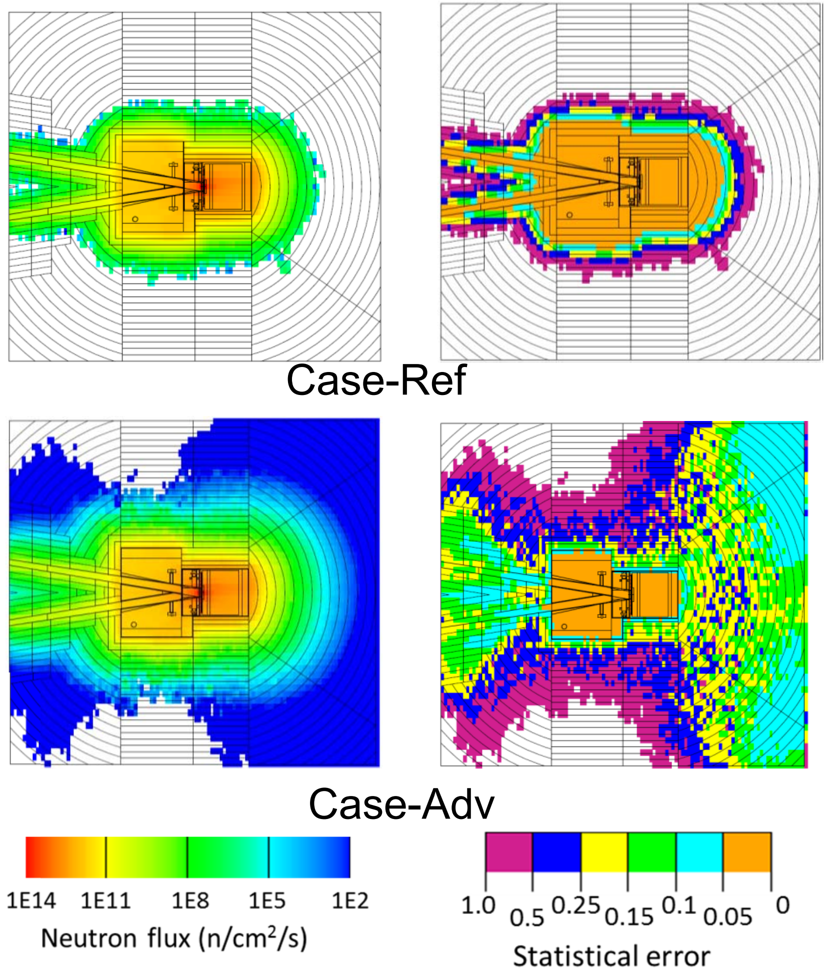


Assessment of ADVANTG for IFMIF-DONES

- Case-Ref
  - Only ~10% of cells has results
  - Statistics < 0.15: 7% of cells
- Case-Adv
  - Only finished 10^7 histories
  - Good statistics in beam up and downstream
  - Statistics < 0.15: 13% of cells
  - Very slow!!

faction of cells with statistical error less than the given statistical error



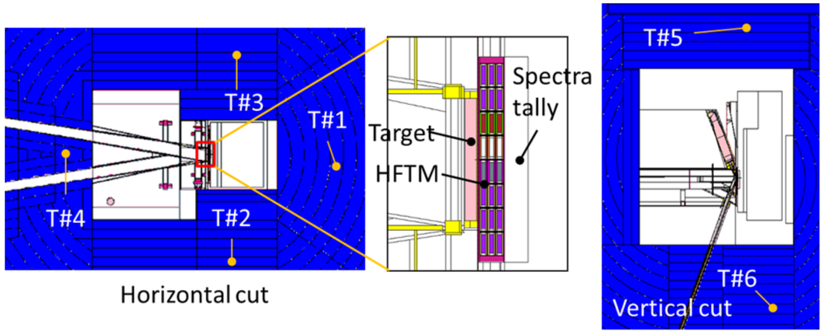


Case-Ref	13999
Case-Adv	54

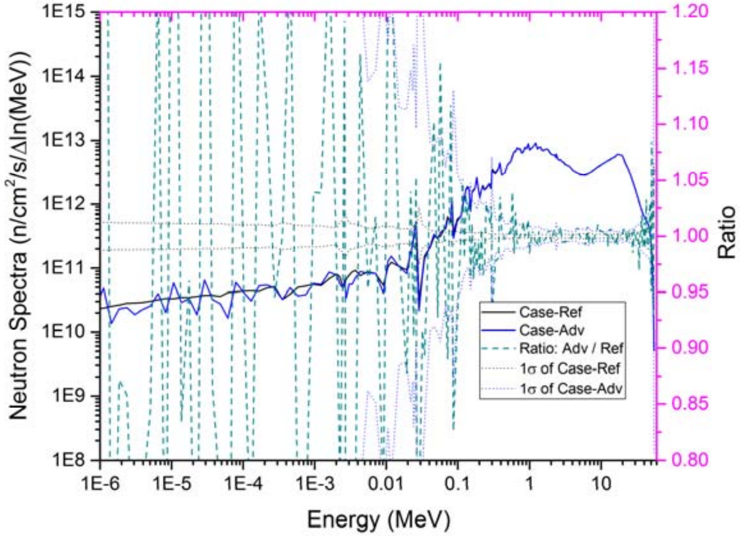
Computation speed (NPS/ CTM)

Assessment of ADVANTG for IFMIF-DONES

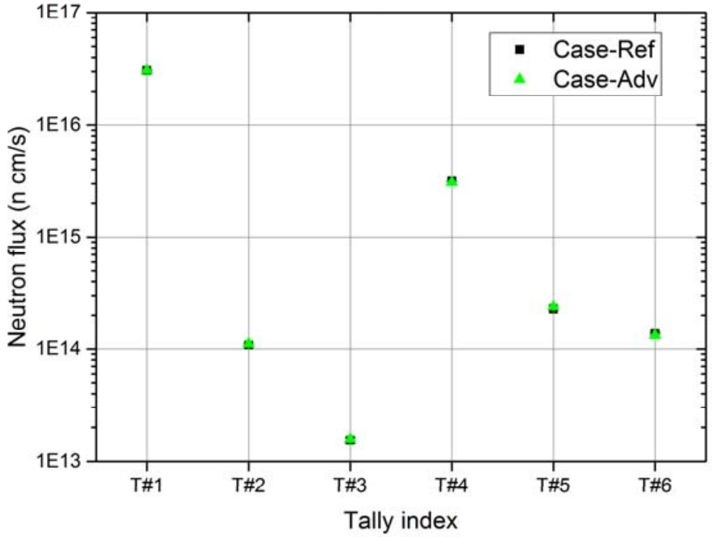
- Spectrum
  - Agreed in high energy range
  - Very large statistics error when E< 0.1 MeV
- Cell tallies
  - Agreed very cell.



Tally positions



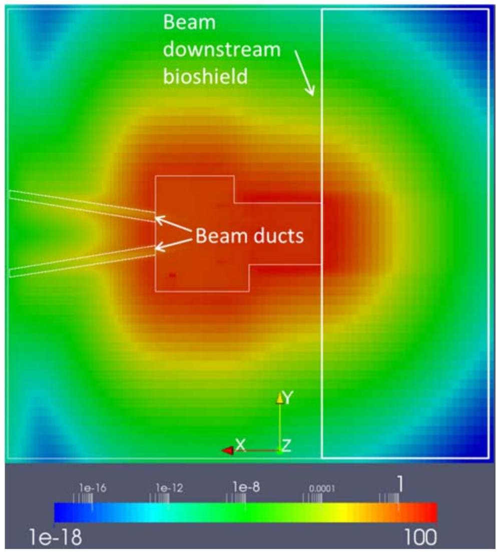
Neutron spectra and ratio



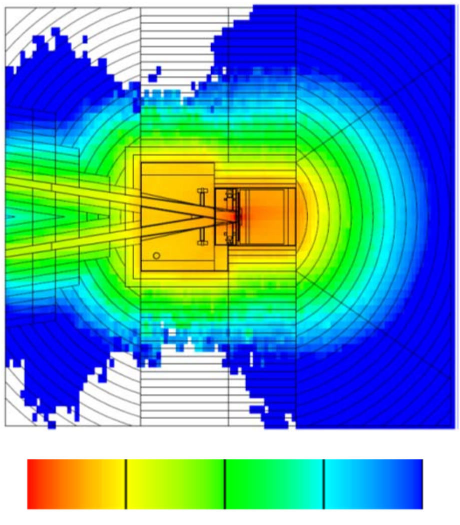
Neutron flux of cell tallies

Improvements: methods and codes

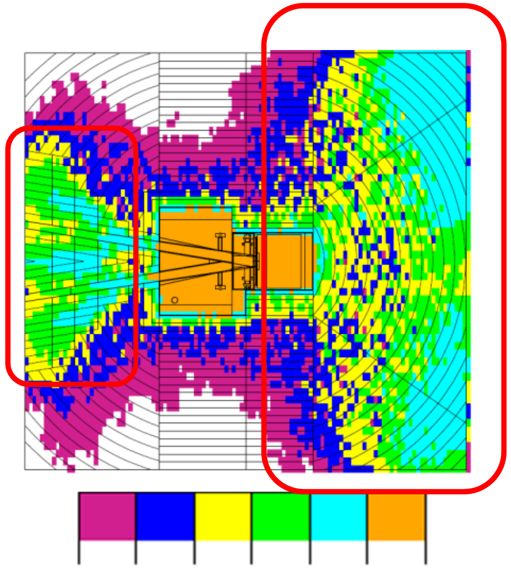
- Issue of computational speed
  - WW lower-bounds does not consistent with the flux level through the beam duct
  - Change of flux: 10^{-2} to 10^{-3}
  - Change of WW: more than 10^{-8}
  - Result in long-time simulation of over-splitting particles (long histories)



WW lower-bounds of group 7 (~0.013 MeV)



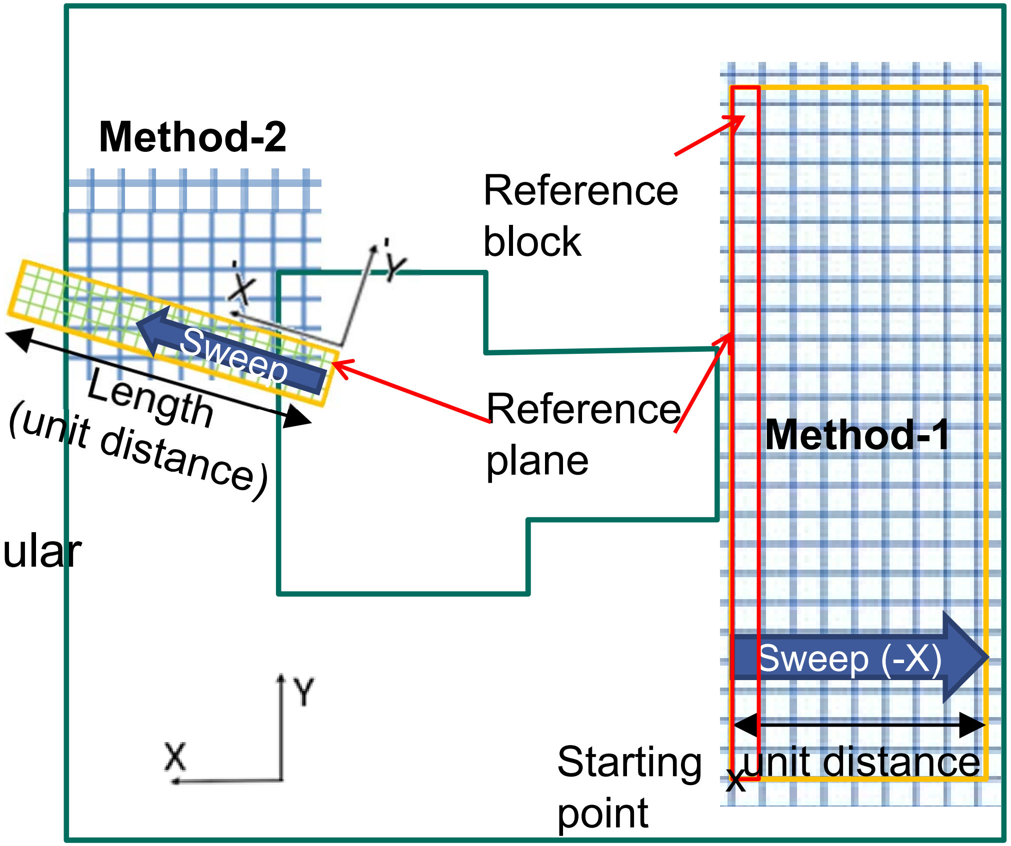
Neutron flux (n/cm²/s)



Statistical error

Improvements: methods and codes

- A WW tuning program
  - A Python script for reading, tuning, writing wwinp file
- Method-1
  - Sweeping a block in X, Y, Z direction
- Method-2
  - Sweeping a tunnel of rectangular or cylindrical shape in any direction
- Linear or exponential tuning
  - Multiplying a factor to orignal value (W_i) or to reference value W_0
  - λ : factor
  - δ : relative distance



$$\boxed{W_i{}' = W_i\lambda\delta}$$ or $$\boxed{W_i{}' = W_i\exp(\lambda\delta)}$$

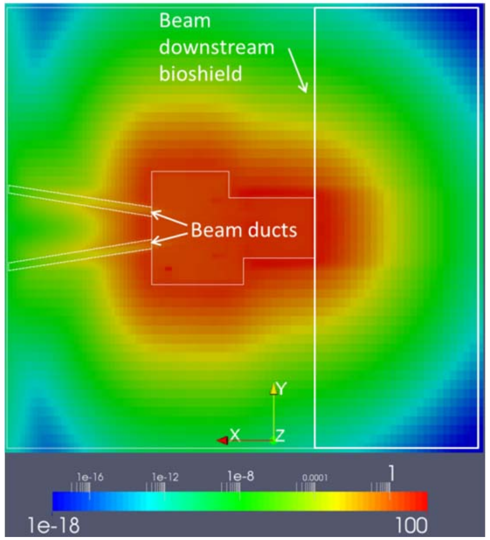
Linear — Exponential

Improvements: methods and codes

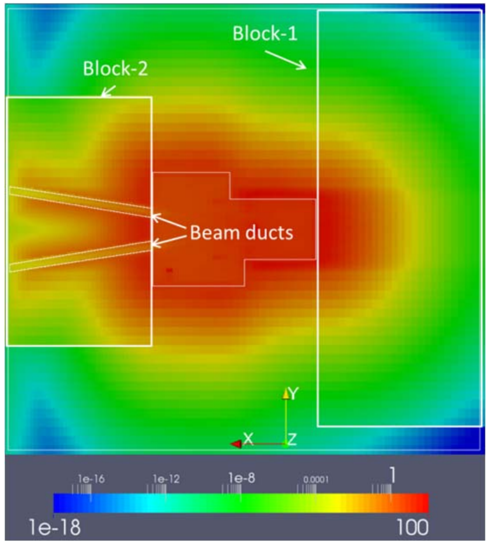
- Tuning of the ADVANTG WW (Case-Tuned)
  - Block-1 : Reduce the over-splitting in the beam downstream
  - Block-2: increase the WW arround the beamduct
  - Beam duct: replace with the in-TC weight

	Block-1	Block-2	Beam duct
Method	Method-1	Method-1	Method-2
Tuning	Exponential	Exponential	Exponential
Multiply	Original value	Original value	Reference value
Factor	6.9	11.5	-6.9
Effect at the last cell	10^3 ↑	10^5 ↑	10^{-3}↓

Before tuning

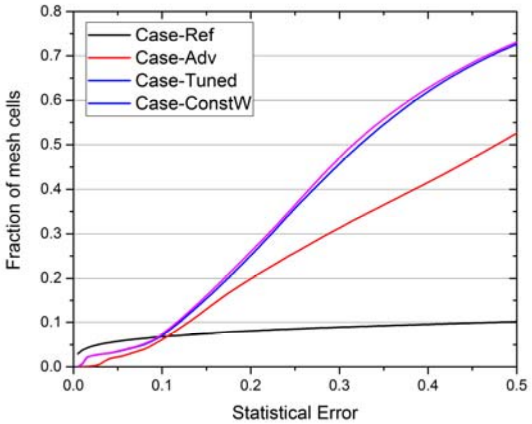


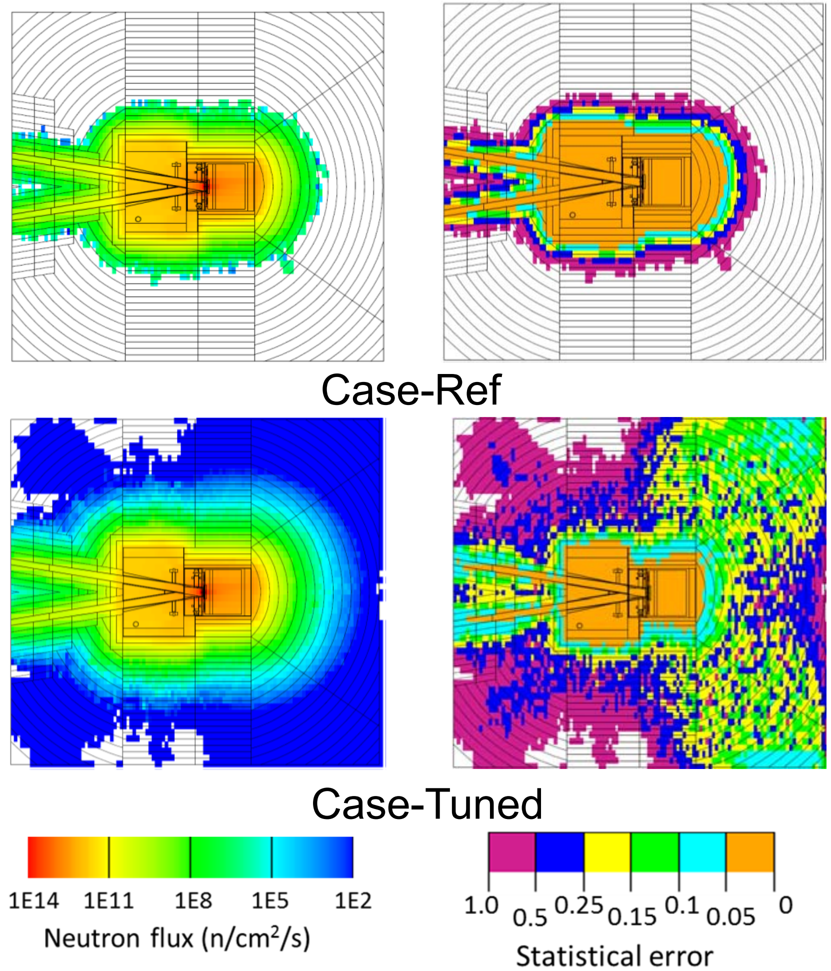
After tuning



Improvements: methods and codes

- Case-Ref
  - Only ~10% of cells has results
  - Statistics < 0.15: 7% of cells
- Case-Adv
  - 1.4 time fast than Case-Ref
  - Long-histories problem imtigated
  - Statistics < 0.15: 15% of cells



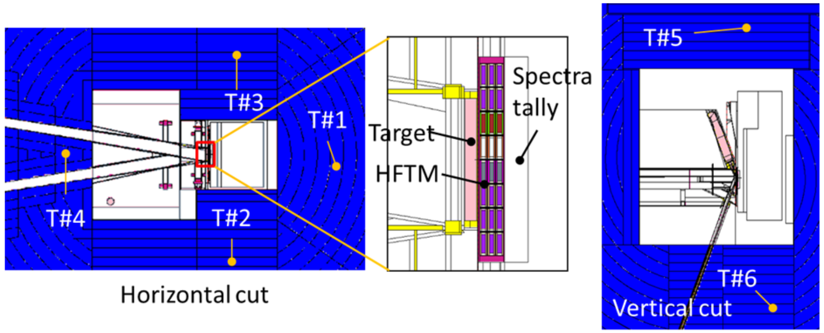


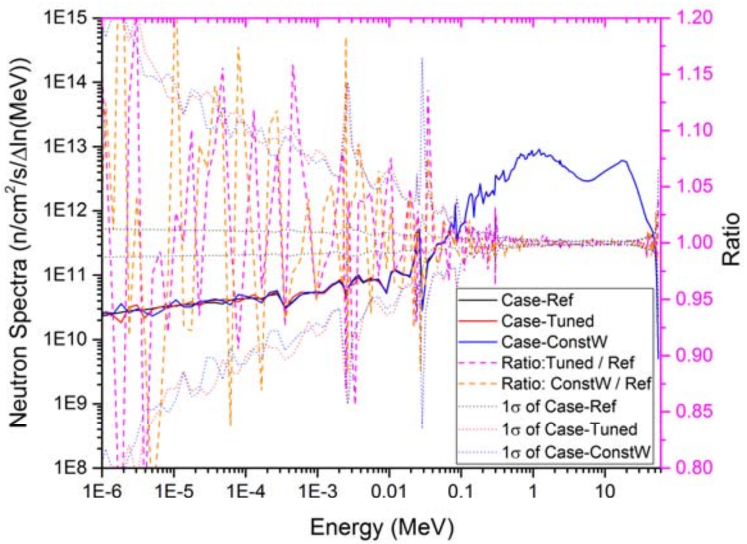
Case-Ref	13999
Case-Tuned	19663

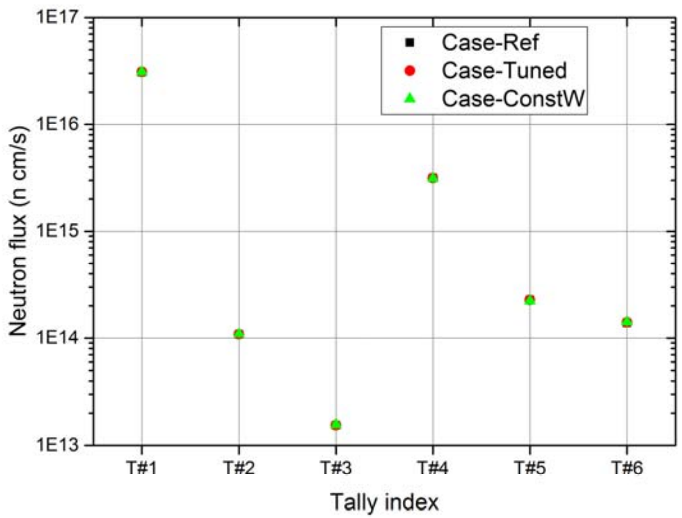
Computation speed (NPS/ CTM)

Improvements: methods and codes

- Spectrum
  - Agreed in high energy range
  - Still large statistics error when E< 0.1 MeV
  - Due to the response-weighted option
- Cell tallies
  - Agreed very cell.







Improvements: methods and codes

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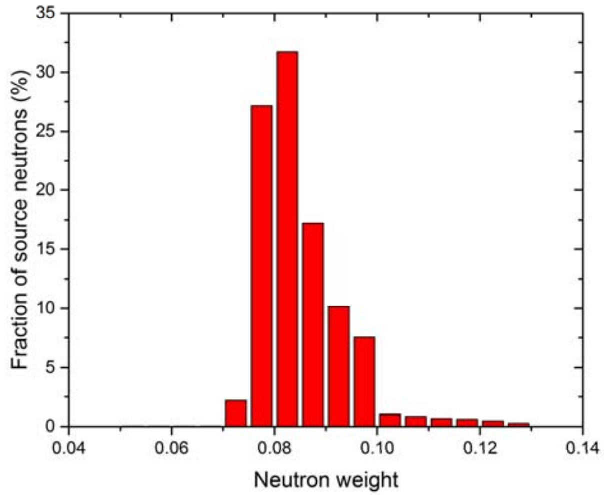
- McDeLicious with constant weight (Case-ConstW)
  - Choosing a ω_0 weight larger than the maximum weight
  - Using the Russian roulette technique
  - Neutron kill: $\omega < \xi\omega_0$, resampling
  - Neutron survived: new weight of ω_0
  - Results renormalized by

$$\eta = 1 - \frac{N_{kill}}{N_{kill}+N_{nps}}\ .$$



  - N_{kill}: mount of neutrons killed
  - N_{nps}: total particle histories.

Improvements: methods and codes

- Case-Ref
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- Case-Adv
  - 1.4 speed up
  - Long-histories problem imtigated
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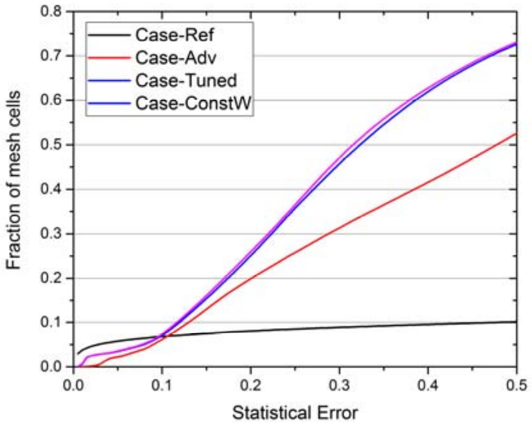
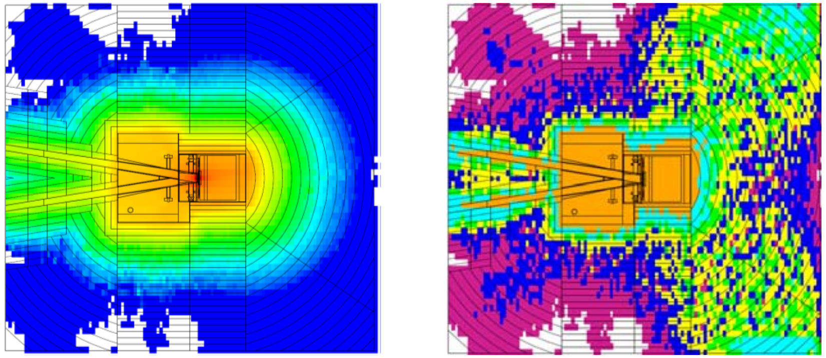
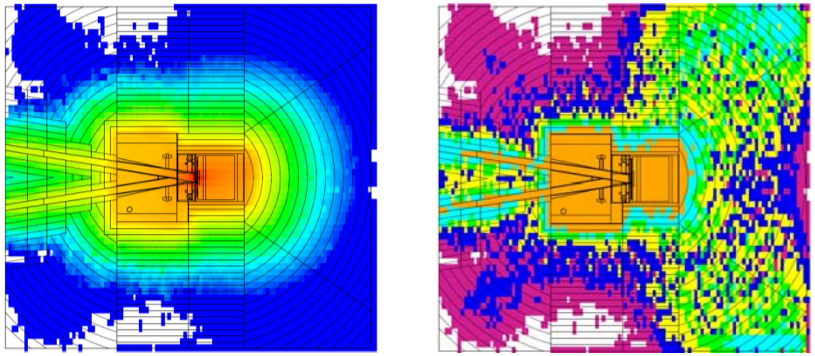
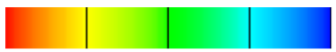




Case-Tuned



Case-ConstW



Case-tuned	19663
Case-ConstW	14176

Computation speed (NPS/ CTM)

Improvements: methods and codes

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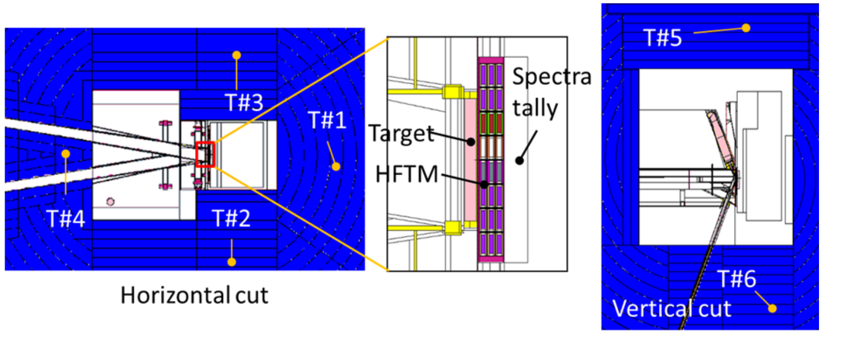

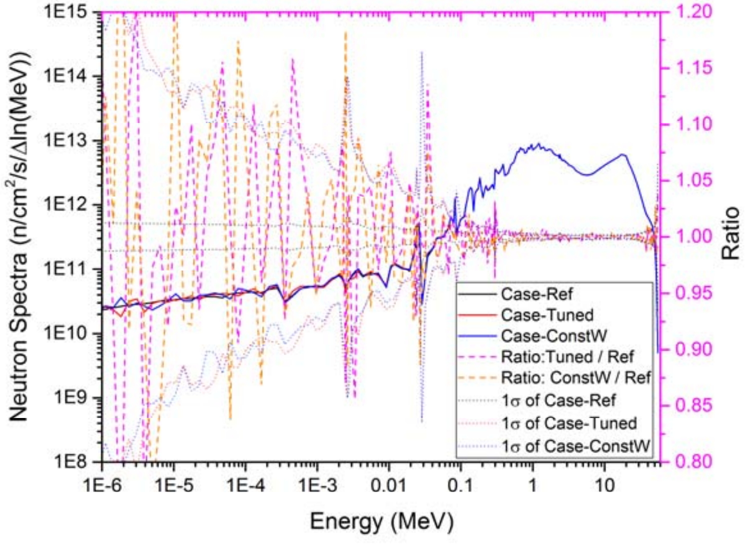

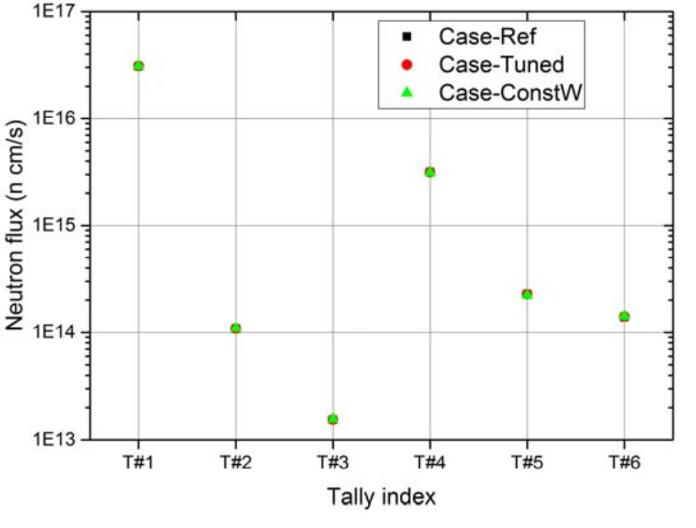

Summary and outlook

- The effect of using an ADVANTG generated WW mesh for the DONES has been assessed.
- The long histories problem has been mitigated by tuning the WW mesh using a python script.
- The MCNP run with the tuned ADVANTG WW mesh has 2 times more mesh tallies cells with statistical error < 15%, the computational speed is 1.4 times faster compared to normal MCNP run.