ORNL

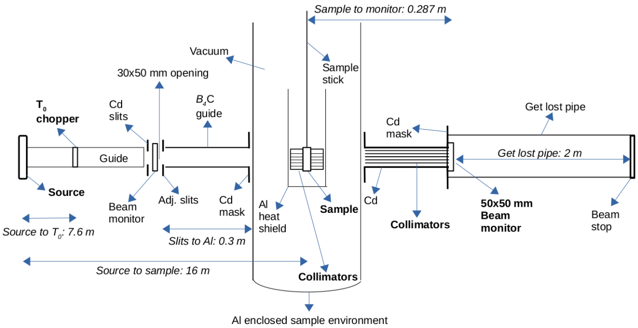
Thermal neutron transmission measurements at ORNL's Spallation Neutron Source

Kemal Ramić, Goran Arbanas, Luke Daemen, Iyad Al-Qasir, Jesse Brown, Chris Chapman, Klaus Guber, Luiz Leal, Hassina Bilheux, Jean-Christophe Bilheux, Kevin Yahne, Shimin Tang, Chen Zhang, Antonio Moreira dos Santos, Jamie Molaison, Chris Ridley, Jasmine Hinton, Trevor Aguirre, José Ignacio Marquez Damian

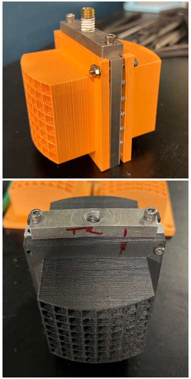
ORNL

SNS Transmission measurements journey: VISION

- ORNL VISION transmission setup:



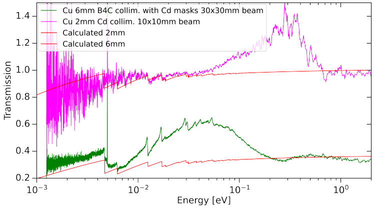
- Short distance ($\approx$ 0.28m from sample to detector). Needs collimation (polymer B_4C or BN 3D printed collimators:



- For background characterization "double notch" technique is used (Cadmium, Indium, and Erbium)

SNS Transmission measurements journey: VISION

- Measured transmission for Copper at VISION:



- Bump was caused by neutron thermalization from scattering in the hydrogen of the collimators.
- Impromptu cadmium collimator proves the cause of the bump.

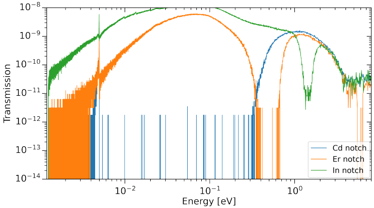
Cons:

+ Short distance, fixable with correct collimation.
+ Detector efficiency really low, 0.1%. Manual sample changes.

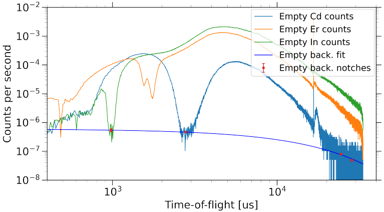
Pros:

+ White beam, no chopped frames.

- Characterization of background:



- Fixed issues seen in a Cd notch due to vertical beam divergence:



OAK RIDGE National Laboratory

SNS Transmission measurements journey: SNAP

- ORNL SNAP transmission setup:

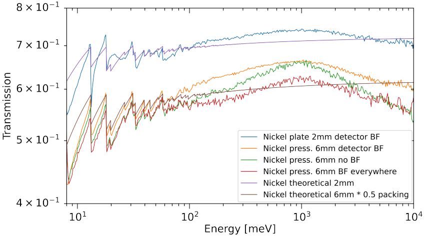
Cons:

+ Detector efficiency really low, 0.5%.
+ Chopped frames. Manual sample changes.

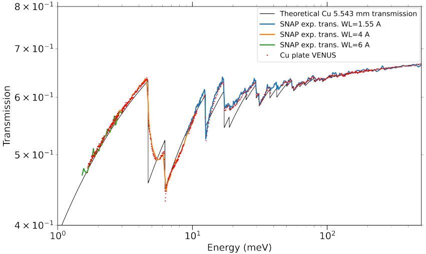
Pros:

+ Long distance.

- Initial measured transmission for Nickel:

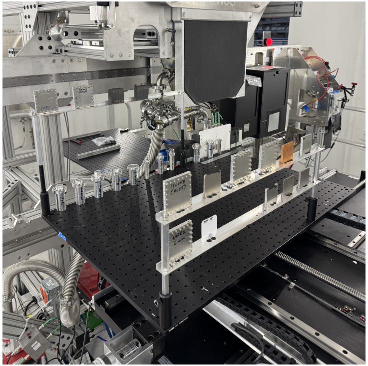


- Final measured transmission for Copper:



OAK RIDGE National Laboratory

SNS Transmission measurements journey: VENUS

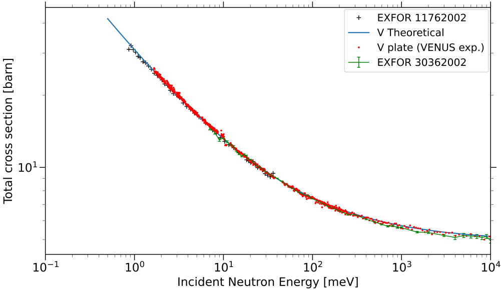


- Sample changer!
- The detectors (TimePix1 and TimePix3 with efficiency up to 70% for thermal neutrons) combined with the flux! This enables smaller beam sizes which rectifies the distance issues.
- Flexibility with the setups!
- Cryostat and furnaces for temperature dependent measurements.

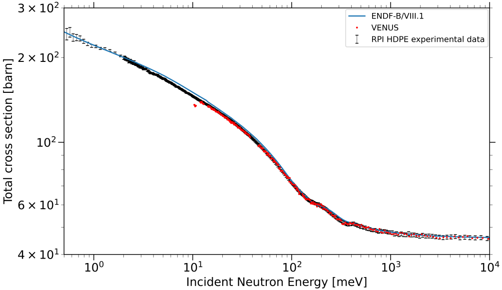
OAK RIDGE National Laboratory

Transmission lessons learned: “traditional” samples

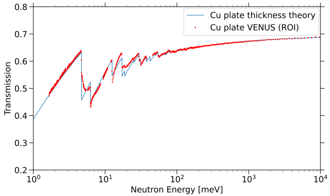
- Vanadium plate:

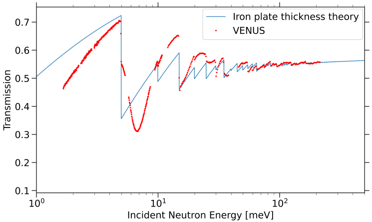


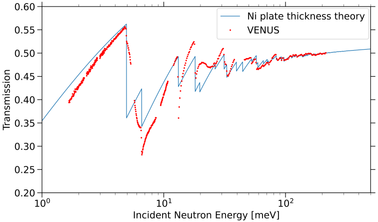
- High density polyethylene:

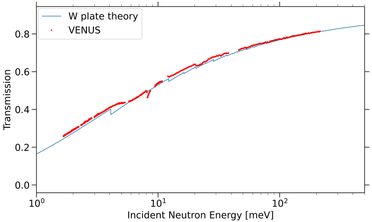


Transmission lessons learned: metallic samples





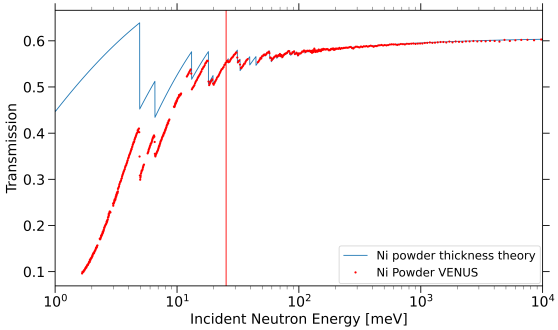




- Metallic samples are not that great for validation purpose!

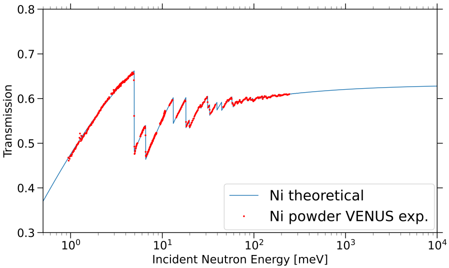
OAK RIDGE National Laboratory

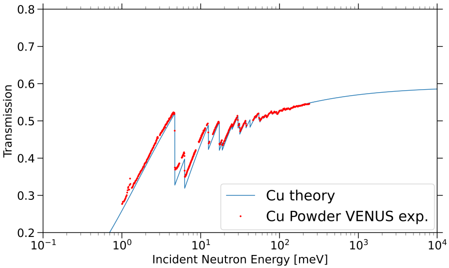
Transmission lessons learned: powder samples



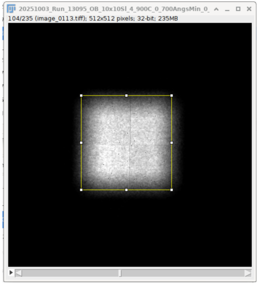
- When working with powders or porous materials, small angle neutron scattering becomes an issue.
- There are three ways to correct for SANS:
  1. Experimental correction
  2. Analytical correction
  3. Neutronics calculation correction

Transmission lessons learned: SANS experimental correction



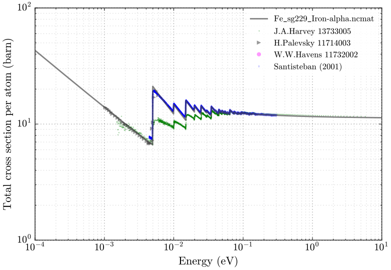


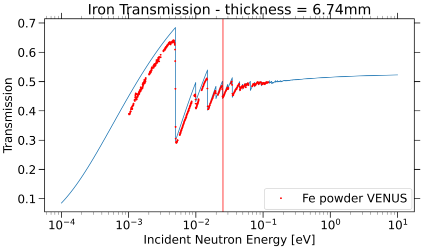
- Methodology proposed by Egelstaff and Petriw.
- Measure the sample as close as possible to the detector.
- Select the region of interest (ROI) that corresponds to the beam size:

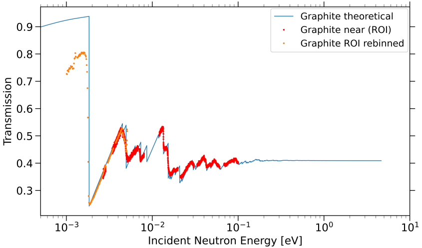


- Seems to work well with the samples which do not have large SANS cross section.

Transmission lessons learned: SANS experimental correction

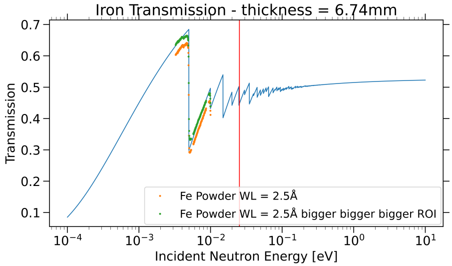


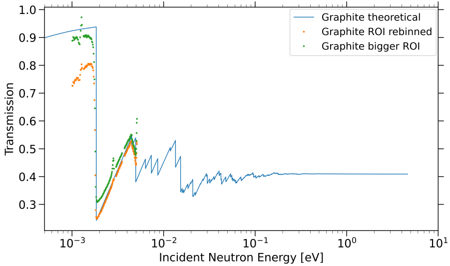




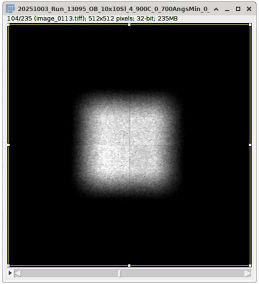
- But for the samples with the strong SANS cross section contribution the method is not enough.

Transmission lessons learned: SANS experimental correction





- Measure the sample as close as possible to the detector.
- Select the region of interest (ROI) that corresponds to the whole detector active area:



- May need to use a smaller beam than 10x10 mm.

Transmission lessons learned: SANS analytical correction

Idea: measured transmission gives a cross section:

$$\sigma_{\mathrm{exp}}(E) \approx \sigma_{\mathrm{t}}(E) + \sigma_{\mathrm{SANS}}(E),$$

where σ_{t} is the intrinsic (no-porosity) model (TSL/NJOY/NCrystal) and σ_{SANS} is removal by small-angle scattering from pores/powders.

Baseline alignment: interpolate $\sigma_{th}(E)$ onto the experimental grid using log E–log σ interpolation to preserve Bragg-edge structure on log scales.

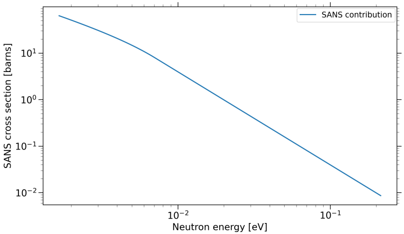
SANS term: assume a 2-parameter porous microstructure: porosity P and pore radius r_P ($R_g = \sqrt{3/5}\, r_P$). For elastic SANS, with neutron wavenumber $k = 2\pi/\lambda(E)$,

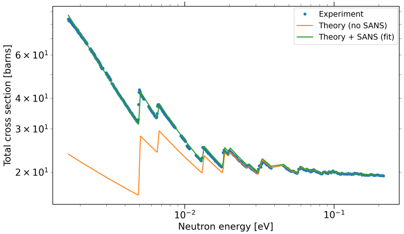
$$\sigma_{\mathrm{SANS,tot}}(E) = \frac{1}{2k^2} \int_0^{2k} q\, I(q)\, dq.$$

Detector acceptance (forward cone): neutrons scattered by $\theta < \theta_{\mathrm{min}}$ remain in the transmitted beam:

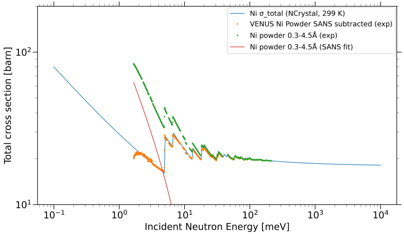
$$q_{\mathrm{min}} = 2k \sin\left(\frac{\theta_{\mathrm{min}}}{2}\right), \qquad \sigma_{\mathrm{SANS,meas}}(E) = \frac{1}{2k^2} \int_{q_{\mathrm{min}}}^{2k} q\, I(q)\, dq.$$

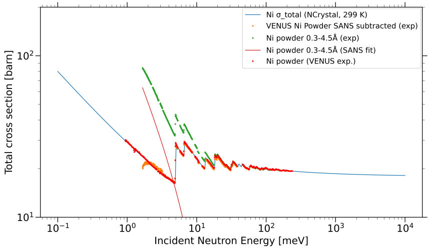
- Methodology proposed by Petriw and Nakayama!

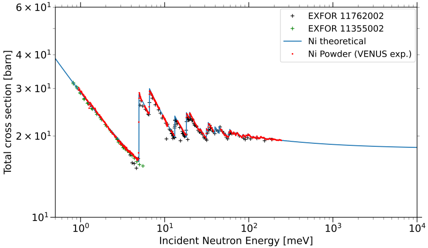




Transmission lessons learned: SANS analytical correction

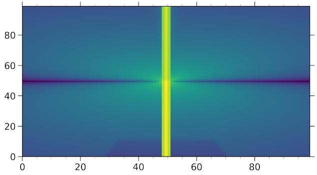




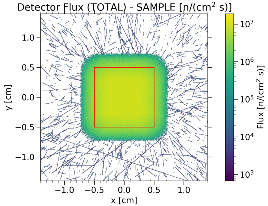


Transmission lessons learned: SANS neutronics correction

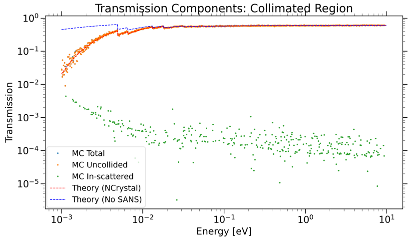
- One could correct using neutronics calculation, for example OpenMC + NCrystal:

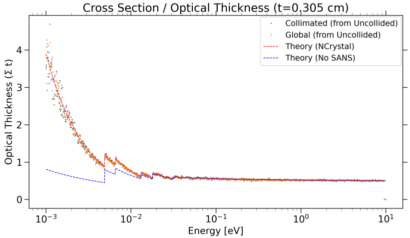


- Digital twin of the experiment:



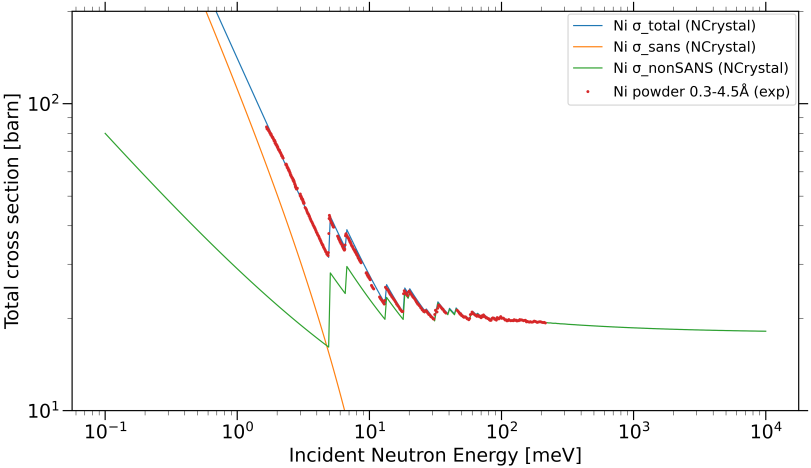
- If one does the calculation at far distance, and adjust the SANS model until transmitted + inscattering transmission matches the measured data:





Oak Ridge National Laboratory

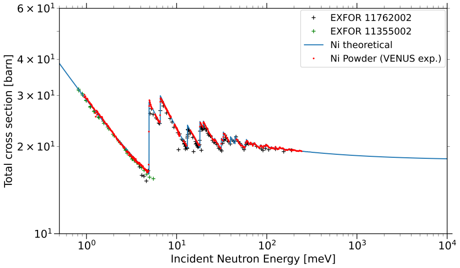
Transmission lessons learned: SANS neutronics correction

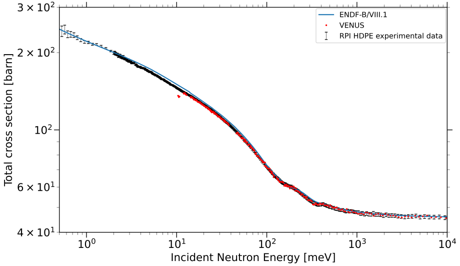


- The neutronics correction works and is possibly more useful than the analytical one.

Summary & Conclusions

- The path to thermal neutron transmission measurements at SNS was long and at times tedious, but it proved highly productive and full of lessons.
- We can do temperature dependent measurements in an 1-2 hours time frame.
- Sample choice is important, but we have found a way around some of the limitations.
- A lot of cross sections coming from ORNL in the near future.
- Resonance transmission measurements possible as well.





OAK RIDGE National Laboratory

Acknowledgements

- This work is supported under the framework of the US Department of Energy/US Nuclear Regulatory Commission Collaboration for Criticality Safety Support for Commercial-Scale HALEU Fuel Cycles Project (DNCSH).
- This work was supported by the Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.
- This research used resources at the Spallation Neutron Source, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory.
- This research used resources at the High Flux Isotope Reactor and the Spallation Neutron Source, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory. The beam time was allocated to VISION on proposal number IPTS-32976.1, IPTS-34177.1. The beam time was allocated to SNAP on proposal number IPTS-32890.1, IPTS-34149.1. The beam time was allocated to VENUS on proposal number IPTS-35167, and IPTS-35407.

VENUS background