# Neutron production in argon and steel

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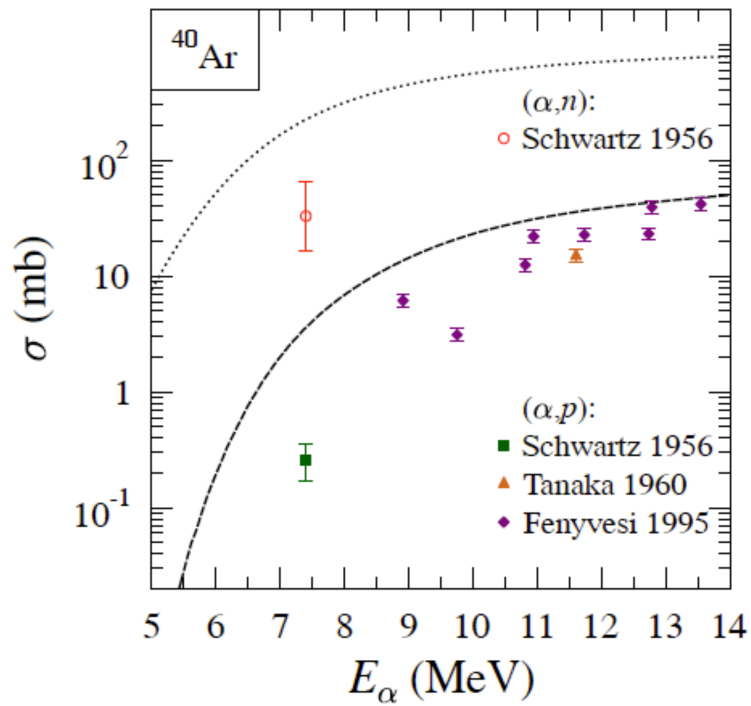
# Remaining questions about backgrounds

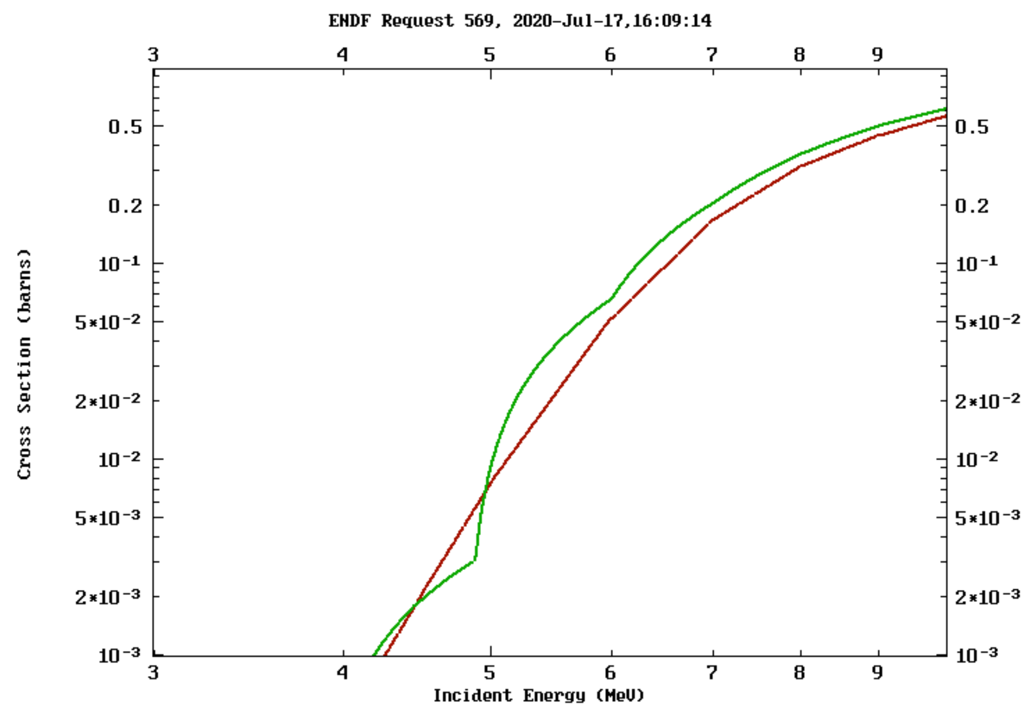
- Review of radioactive backgrounds, 2019
  - Recommendation 4 – ($\alpha$, $n$) in LAr: "Committee recommends measuring the cross-section in a dedicated small experiment in order to obtain reliable prediction of the background rate."
    - Plans exist but this is not a major issue.
  - Recommendation 7 – Solar Neutrino Anomaly Measurement with DUNE: "Given the uncertainty in the neutron transport model and production via radon-supported alpha-induced reactions (due to lack of actual cross-section measurements) the predictions are very uncertain to perhaps a factor of 5-10."
    - Uncertainty in the ($\alpha$, $n$) neutron yield is about 20-30%.
- Open topics from 2019 review
  - b. ($\alpha$, $n$) backgrounds produced in LAr and cryostat materials were not well-characterized in the 2019 review. An update is requested. Do we need to measure this? Please update expected backgrounds.
    - Neutron production in ($\alpha$, $n$) reactions will be shown here.
- Alpha rate from radon (progeny) decay in LAr, as well as neutron transport and detection are subject of separate studies (not reported here).

# Code

- W.B. Wilson, et al., SOURCES4A: a code for calculating ($\alpha$,$n$), spontaneous fission, and delayed neutron sources and spectra, Technical Report LA-13639-MS, Los Alamos, 1999.
- Modifications/additions, explained in Tomasello et al. NIMA, 595 (2008) 431.
- Thick target neutron yield: the size of the material sample is much bigger than the range of alphas; edge effects are neglected.
- Uniform distribution of contaminants within the material.
- Code validated by comparison of cross-sections with experimental data.
- Uncertainty: up to 20-30% (differences between models and data sets) for most isotopes tested.
- Latest update at the ($\alpha$, $n$) workshop at CIEMAT (Madrid, November 2019): https://agenda.ciemat.es/event/1127/contributions/2227/attachments/1691/2074/neutrons-alphan-nov2019.pdf
- Paper published: Kudryavtsev et al. *Nucl. Instrum. Meth. A* 972 (2020) 164095; e-Print: 2005.02499 [physics.ins-det].

# Cross-sections for argon




- Q-value: -2.28 MeV, threshold: 2.51 MeV; Coulomb barrier (proximity barrier): 5.5 MeV.
- Left: P. Mohr. Eur. Phys. J. A (2015) 51: 56.
- Right: TALYS (TENDL-2019, green), EMPIRE2.19 (brown, used here).
- 20% difference for most energies of interest.

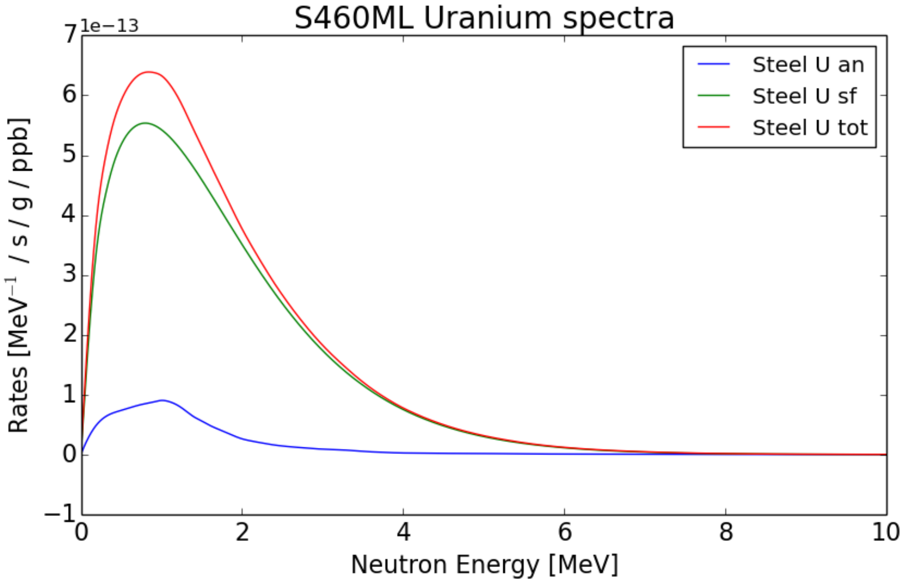
# Neutrons from argon

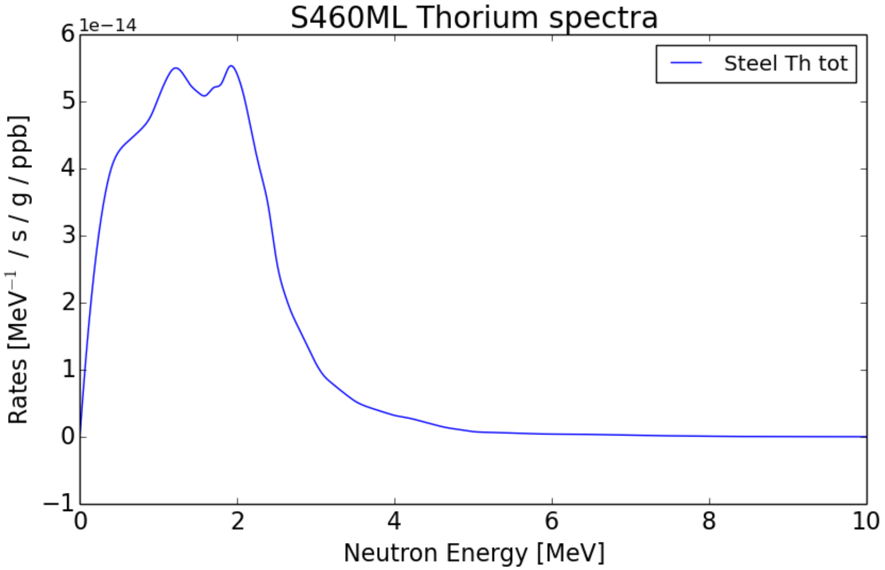
- For $^{238}U$+$^{235}U$ chains in equilibrium the ($\alpha$, n) yield is $1.46\times10^{-10}$ n/g/s/ppb; probably unrealistic: U/Th will be removed from the target during circulation.
- For all alpha decays starting from $^{222}Rn$ and below: $1.37\times10^{-10}$ n/g/s/ppb (the result is normalised to the concentration of natural uranium of 1 ppb assuming secular equilibrium; to convert this into 'per mBq/kg':
  - $^{238}U$: 1 Bq/kg = 80.34 ppb
  - $^{232}Th$: 1 Bq/kg = 246.3 ppb
- For $^{210}Po$ alphas only: $2.22\times10^{-12}$ n/g/s/ppb (normalised to 1 ppb of U).
- For $^{232}Th$ chain in equilibrium: $8.71\times10^{-11}$ n/g/s/ppb (unrealistic).
- Rn and progeny can give some neutron background if in the liquid (before being removed during circulation) or attached to the walls.
- Assume 1 mBq/kg of $^{222}Rn$: $10^{-3}$ Bq/kg × $1.7\times10^{7}$ kg = $1.7\times10^{4}$ Bq.
- Neutron production rate: $1.37\times10^{-10}$ n/g/s/ppb × 80.34 $\times10^{-3}$ ppb × $1.7\times10^{10}$ g = 0.19 n/s (assuming 1 mBq/kg of radon chain in equilibrium) – probably subdominant to external neutrons.
- In the calculations above, the cross-section at 7.5 MeV is 242 mb, well above the experimental point.

# Neutrons from steel (S460ML)

- Spontaneous fission of U-238:
  - $1.353 \times 10^{-11}$ neutrons/g/s/ppb (neutrons per gram per second per ppb of U).
- Mainly iron (assumed 95.4%).
- $(\alpha, n)$ reactions:
  - $^{238}U + ^{235}U$ chains in equilibrium: $1.50 \times 10^{-12}$ n/g/s/ppb (mainly late chain)
  - $^{232}Th$: $1.28 \times 10^{-12}$ n/g/s/ppb.
  - Much less than in SS316L: $5.70 \times 10^{-12}$ n/g/s/ppb.
- Conversion:
  - $^{238}U$: 1 Bq/kg = 80.34 ppb
  - $^{232}Th$: 1 Bq/kg = 246.3 ppb
- Assume 1 Bq/kg of natural U in 1 kt of steel.
- Neutron production rate: $1.50 \times 10^{-12}$ n/g/s/ppb $\times$ 80.34 ppb $\times$ $10^{9}$ g = 0.12 n/s – subdominant to external neutrons.

# Neutron spectra from steel




- Neutron energy spectra from steel.