A Monte Carlo study on neutron activation in neutron detectors with Ar/CO_2 counting gas

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Outline

- ESS: brightest spallation source
- High intensity:
  - Higher signal provided
  - Higher activation
    - Nuclear waste production
    - Activity emission
    - Gamma radiation:
      background for measurement and occupational exposure

- ^{3}He replacement with B_4C-Ar/CO_2 detectors
  - New sources of activation:
    - Large volume Ar/CO_2
    - Aluminium frame → **Activity study needed**

Overview on Ar activation

- Ar activation is known as an issue in several areas:
  - Nuclear power plants
  - Research reactors
  - Accelerator tunnels

B. J. Jun, et al., Nuclear Engineering and Technology (2014) Vol. 42 (2).
M. Hoq, et al., Journal of Environmental Radioactivity 153 (2016) 68-72.
C. Rojas-Palma, et al., DOI: 10.1093/rpd/nch020
B. Lauritzen, et al. Int. J. of Environmental and Pollution 20 (1-6) (2013) 47-54.
https://www.cdc.gov/nceh/radiation/savannah/Chapter_04-3.pdf
https://digital.library.unt.edu/ark:/67531/metadc678287/

- Permanent activity emission during normal operation
  - Airborne radionuclides
  - ^{41}Ar main contributor:
    - thermal neutron capture in ^{40}Ar (99.3% in natural Ar)
  - Natural Ar in air or air dissolved in cooling water

Few 1000 GBq/year activity release

↓

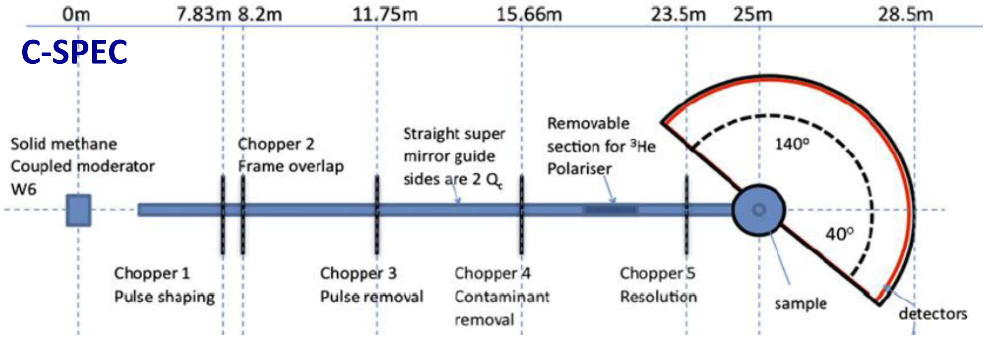
Argon in presence of neutron have to be studied for activation

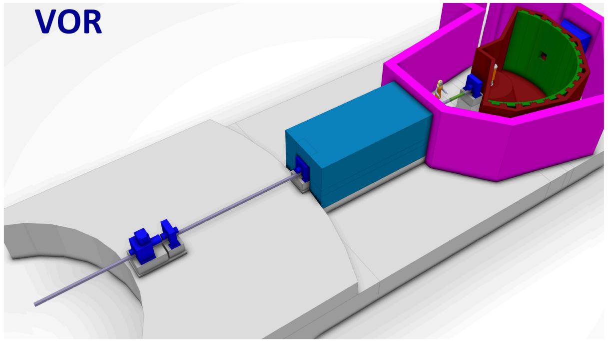
Large area detectors at ESS with Ar/CO_2

A. Khaplanov et al.
http://dx.doi.org/10.1016/j.nima.2012.12.021

- VOR, C-SPEC, T-REX @ ESS
  - Chopper spectrometers with large area detectors
  - Multi-Grid detector (*ILL/ESS/LU collaboration*): $^{10}B_4C$ converter based detector with Ar/CO_2
  - Continuous counting gas flow

Large Ar/CO_2 counting gas volumes exposed to neutron radiation (V~5-10 m^3)





Neutron activation study

- Neutron induced gamma background:
  - Prompt gamma
  - Decay gamma
- Activity production

- Activation study:
  - General Ar/CO_2 detector
  - Standard ESS operational conditions
  - MCNP6.1 simulation
    - Prompt gamma spectrum
    - Decay gamma calculation with Table of Isotopes
  - Analytical calculation:
    - Prompt: IAEA PGAA Database
    - Decay gamma calculation with Table of Isotopes

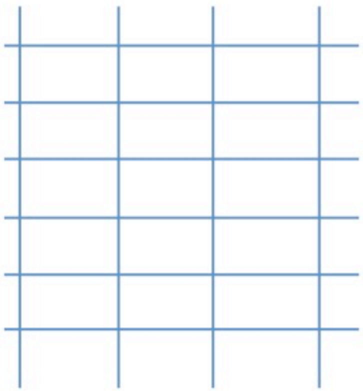


Table of Isotopes: http://nucleardata.nuclear.lu.se/toi/
IAEA Prompt Gamma Activation Analysis Database: https://www-nds.iaea.org/pgaa/

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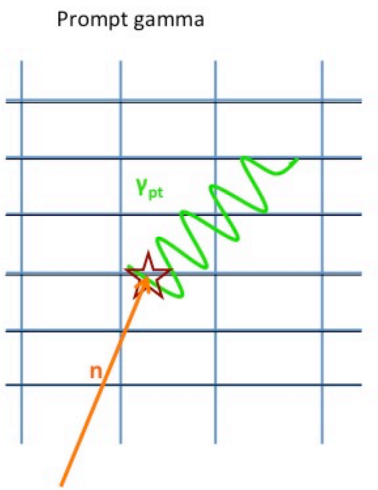

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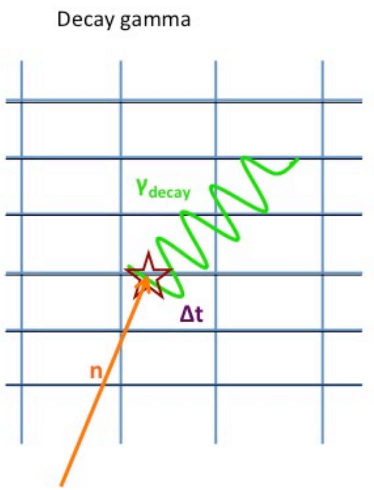

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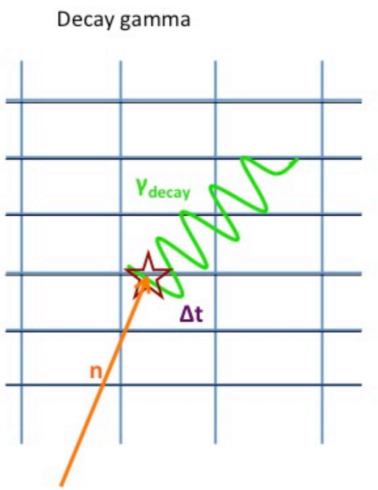


Cross section libraries

Table of Isotopes: http://nucleardata.nuclear.lu.se/toi/
IAEA Prompt Gamma Activation Analysis Database: https://www-nds.iaea.org/pgaa/

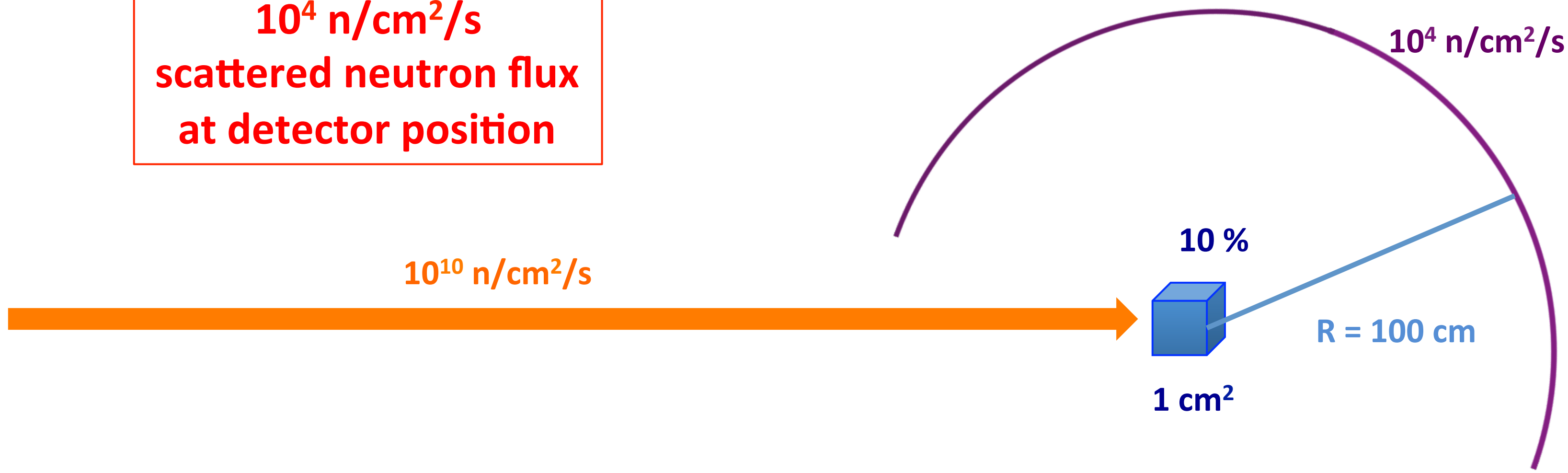
Assumptions and conditions

Standard operational conditions for ESS

- Estimation of irradiating neutron flux
  - Various fluxes at sample position (VOR, T-REX, C-SPEC): conservative estimation: 10^{10} n/cm²/s
  - 1-10 % scattering on sample
  - 1 cm² sample surface
  - R = 100 cm smallest realistic sample-detector distance → 10^5 cm² sphere surface

10^9 n/s scattered neutron

10^4 n/cm²/s scattered neutron flux at detector position

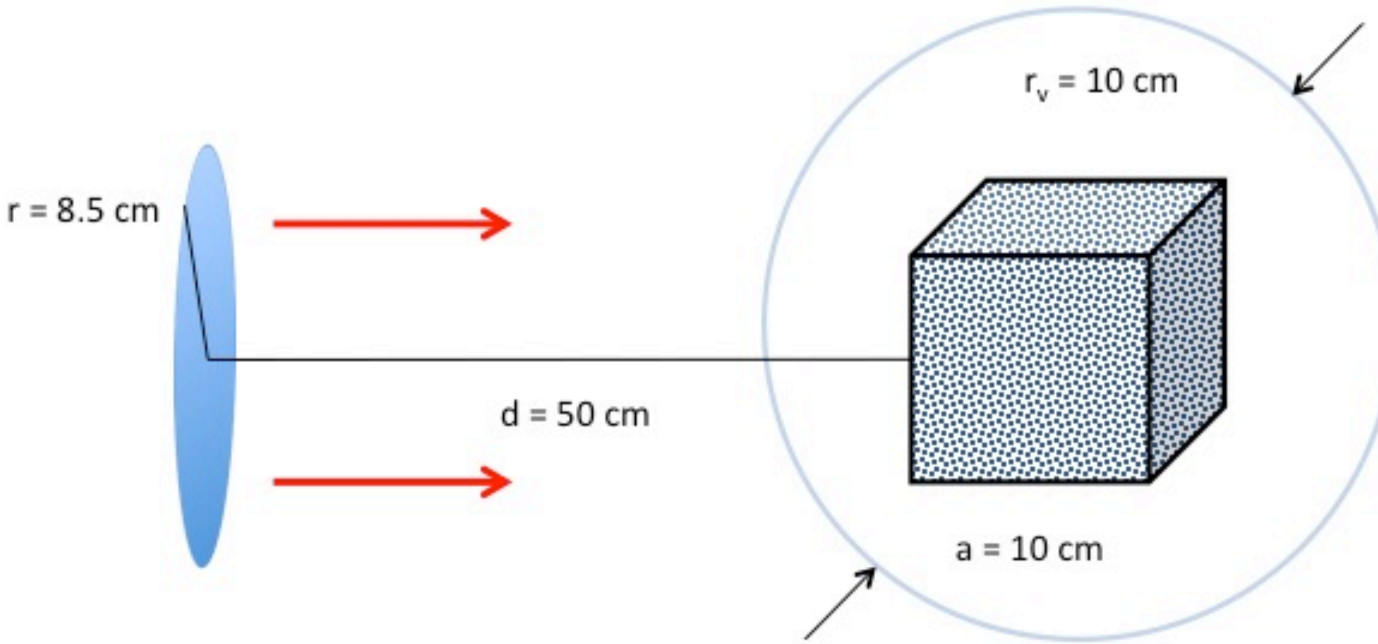


Assumptions and conditions

- Ar/CO_2 detector model for simulation and calculation:
  - 10 x 10 x 10 cm^3 gas cube
  - 5 mm thick aluminium frame, Al5754 alloy
  - r = 8.5 cm monoenergetic pencil beam
    - 0.6, 1, 1.8, 2, 4, 5, 10 Å

- $t_{irr} = 10^6$ s irradiation time
  (typical spallation source operation cycle)
- $t_{cool} = 10^7$ s cooling/decay time

Assumptions and conditions



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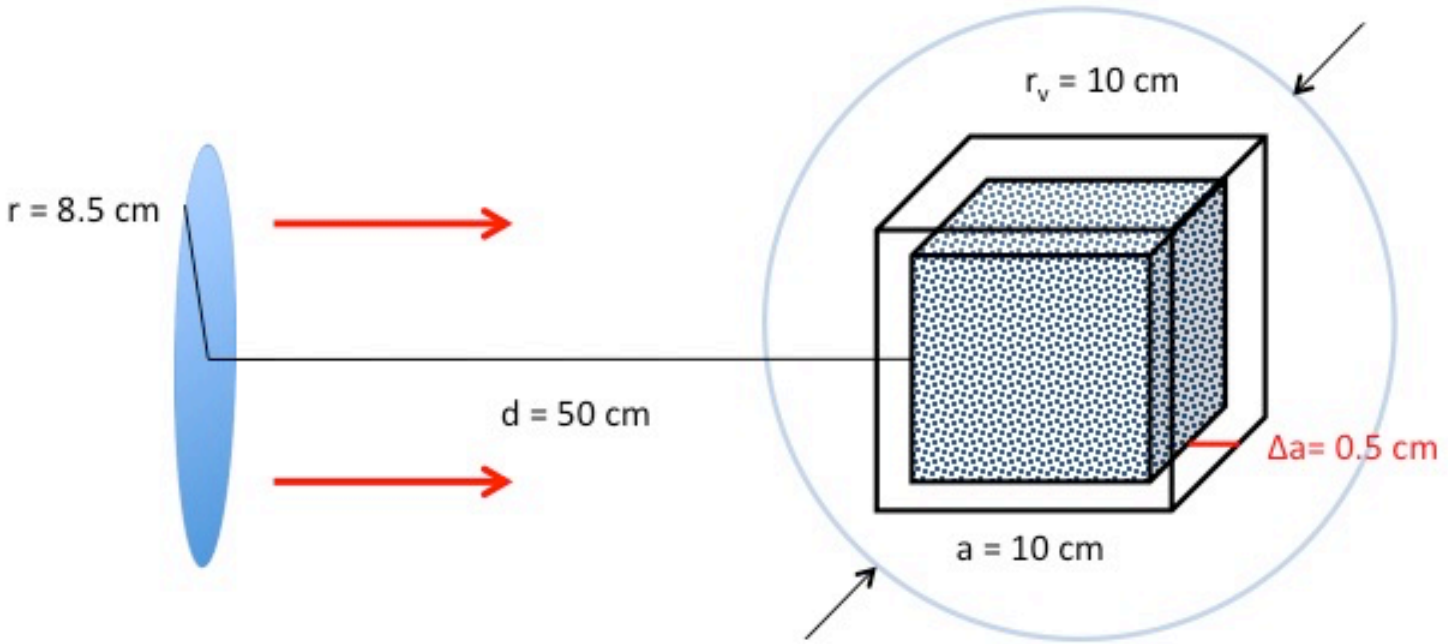

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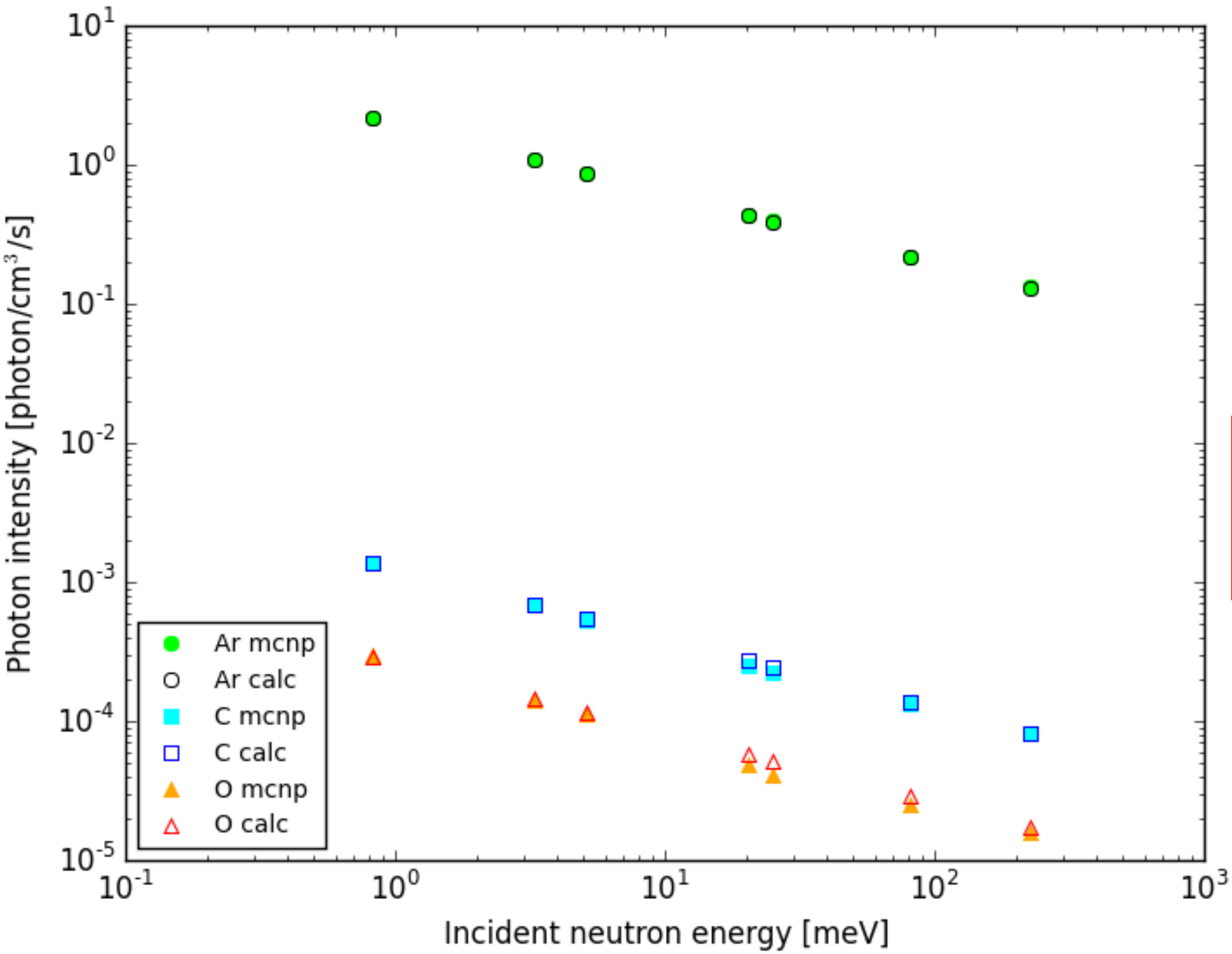
Calculated and simulated prompt and decay gamma spectra and activity

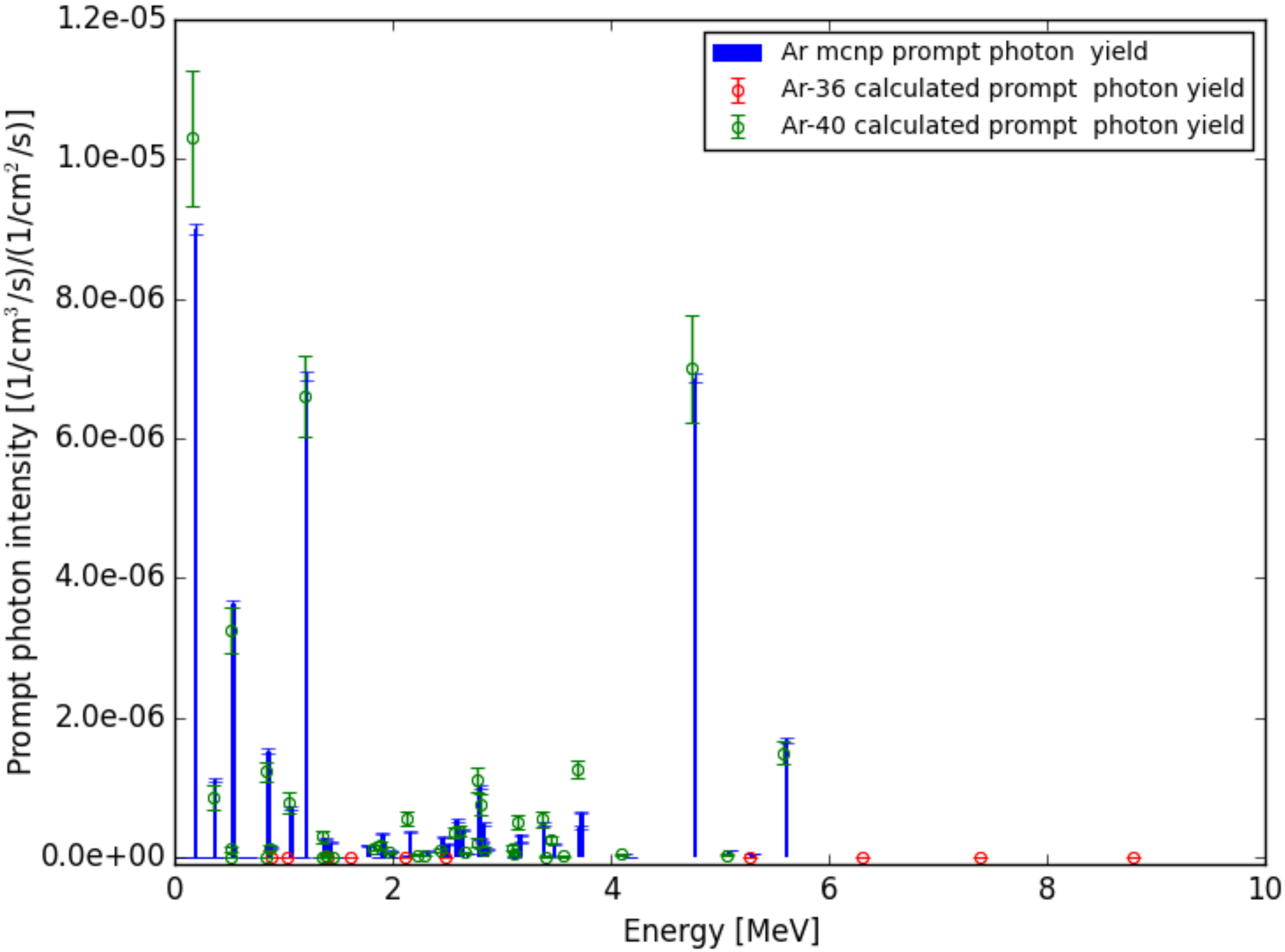
Calculated and simulated prompt photon intensity in Ar/CO_2



Agreement between calculated and simulated photon yield

With the proper databases, analytical calculations can be replaced with MCNP simulation

Calculated and simulated prompt photon spectra in Ar

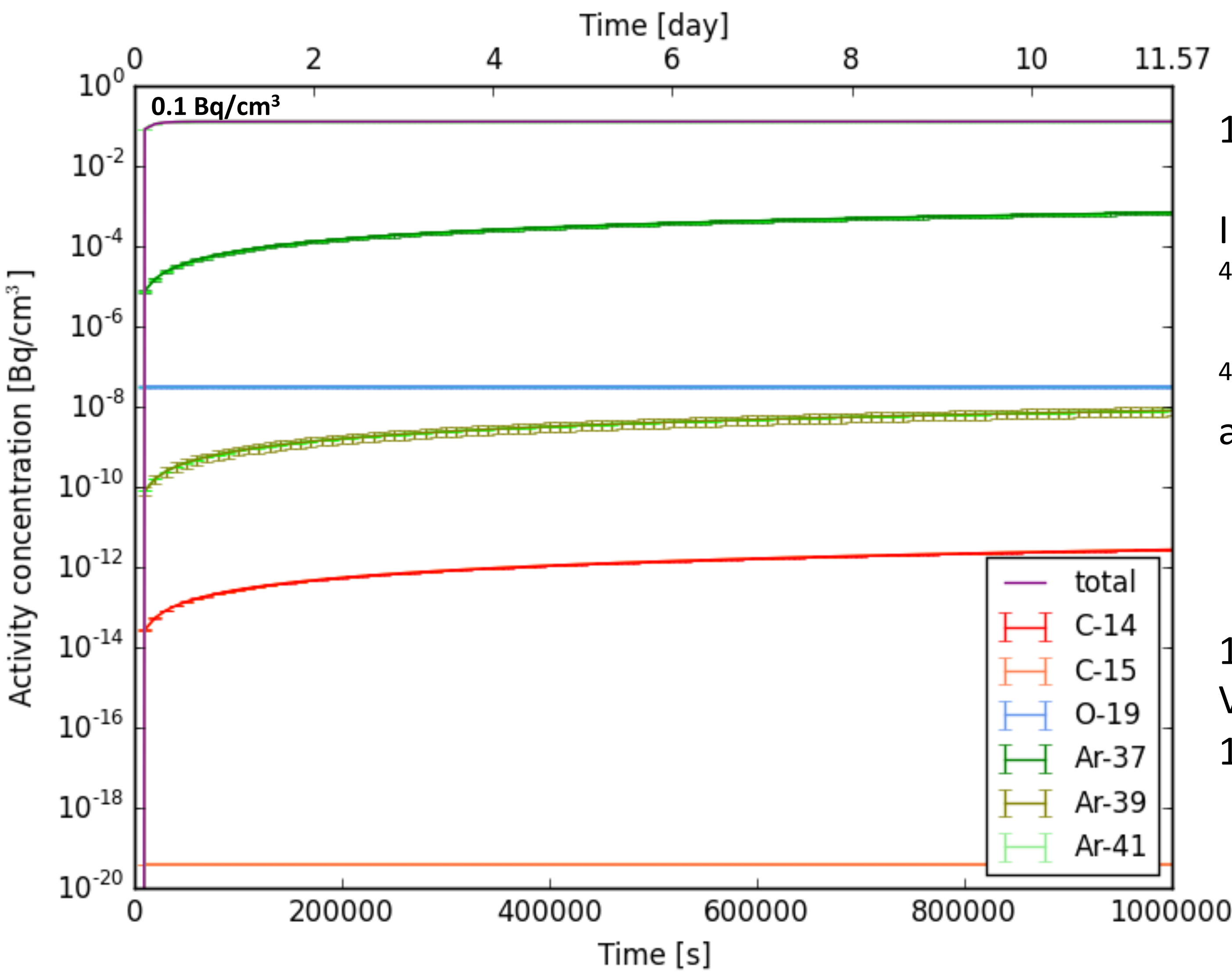


1.8 Å, normalised to incident flux

Agreement between calculated and simulated spectra

With the proper databases, analytical calculations can be replaced with MCNP simulation

Activity build up in Ar/CO_2



1.8 Å

Instant
^{41}Ar background

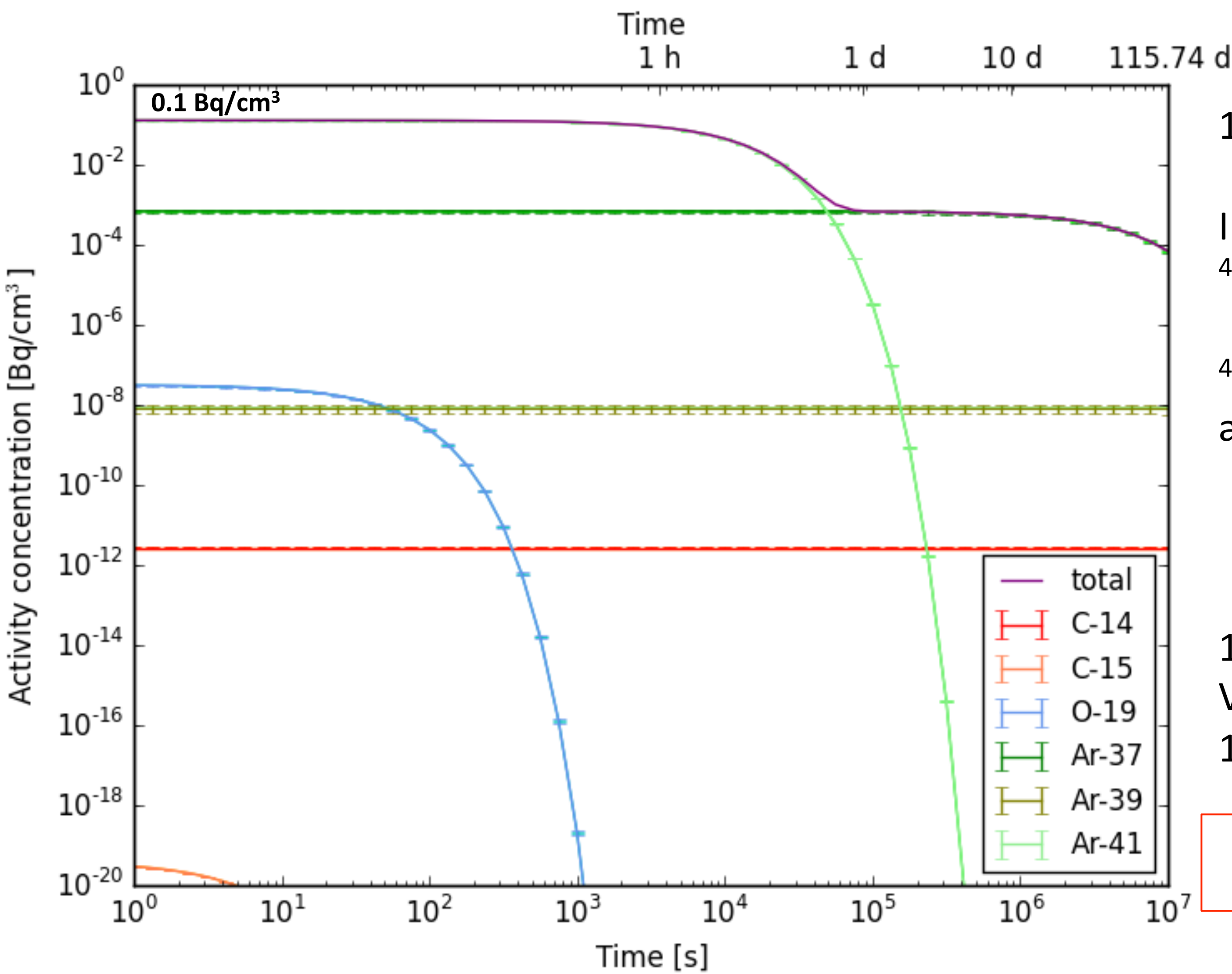
^{41}Ar activity saturates at **128 mBq/cm³**

↓

low

1 detector volume/day:
V ~ 10 m^3
1.28 x 10^6 Bq/day

Activity decay in Ar/CO_2



1.8 Å

Instant
^{41}Ar background

^{41}Ar activity saturates at **128 mBq/cm³**

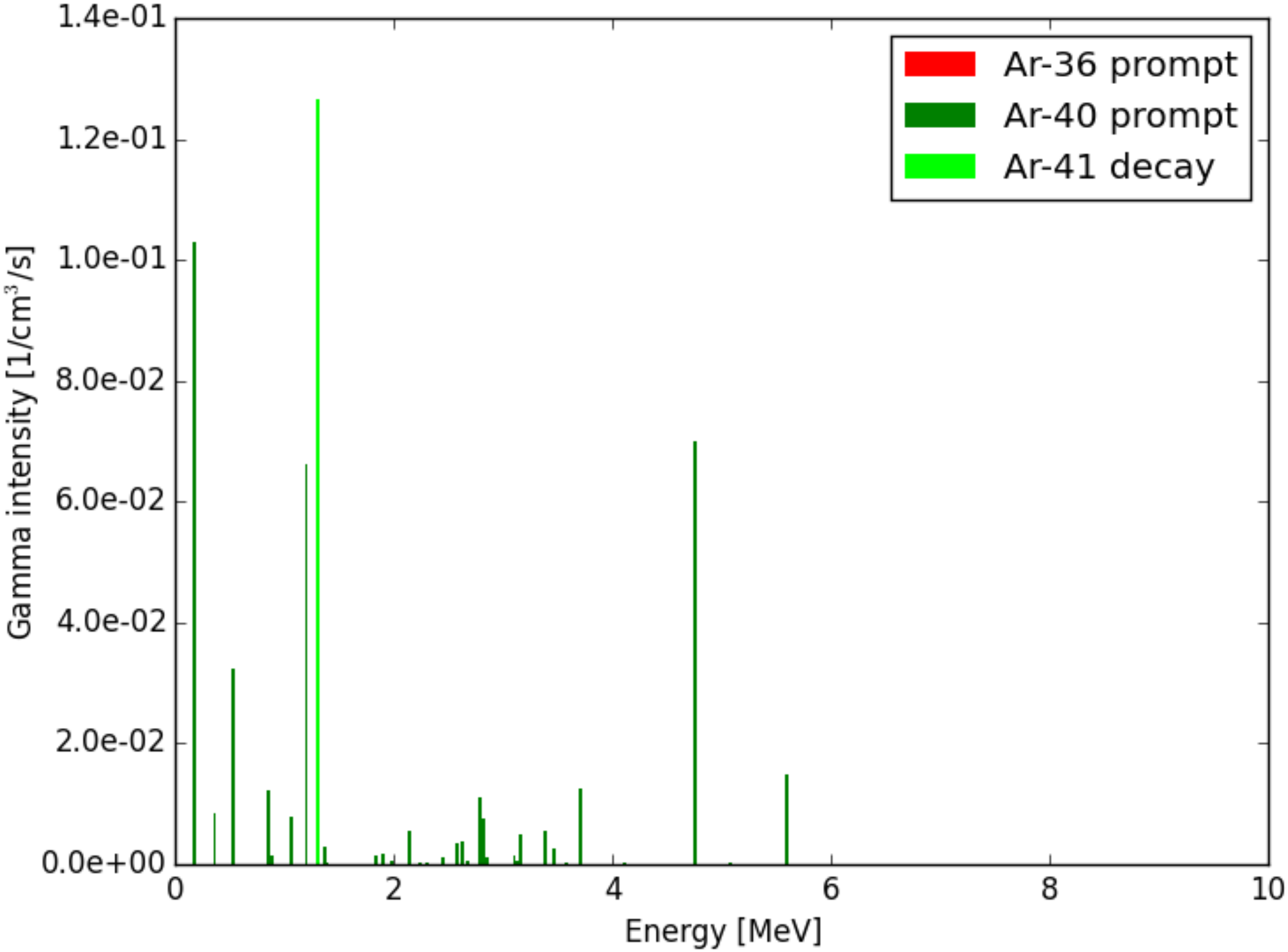
↓

low

1 detector volume/day:
V ~ 10 m³
1.28 x 10⁶ Bq/day

Negligible emission with 1 day cooling

Calculated prompt and decay photon spectrum in Ar

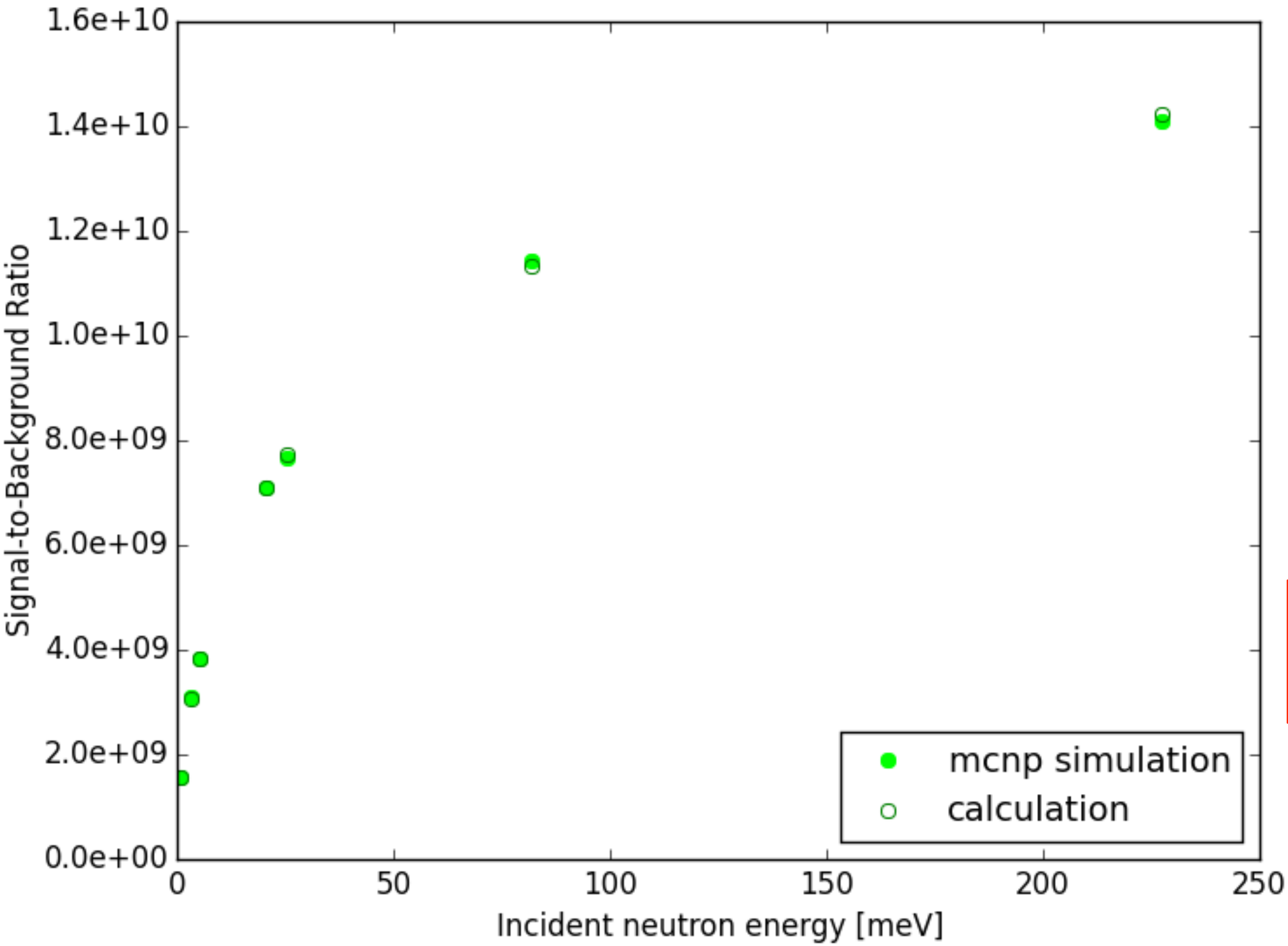


1.8 Å

Comparable prompt and decay gamma yield

Considerable decay gamma background during operation

Signal-to-(neutron-induced gamma background) Ratio



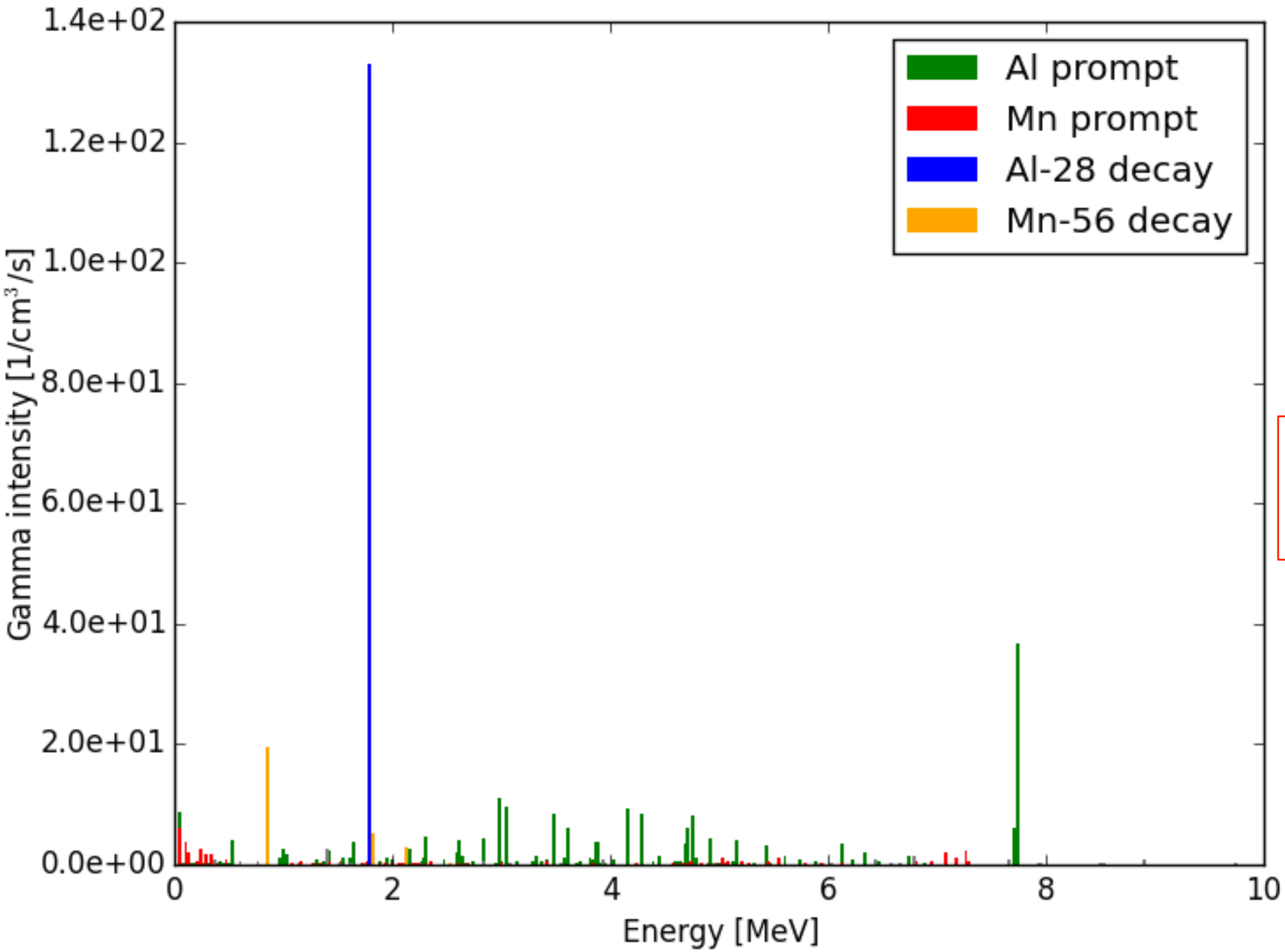
Multi-Grid detector as an example

SBR changes between 10^{9}-10^{10} for the whole energy range

The gamma background is negligible even for beam monitors (10^{-5} efficiency)

The gamma background is negligible in terms of the measured signal

Calculated prompt and decay photon spectrum in Al5754

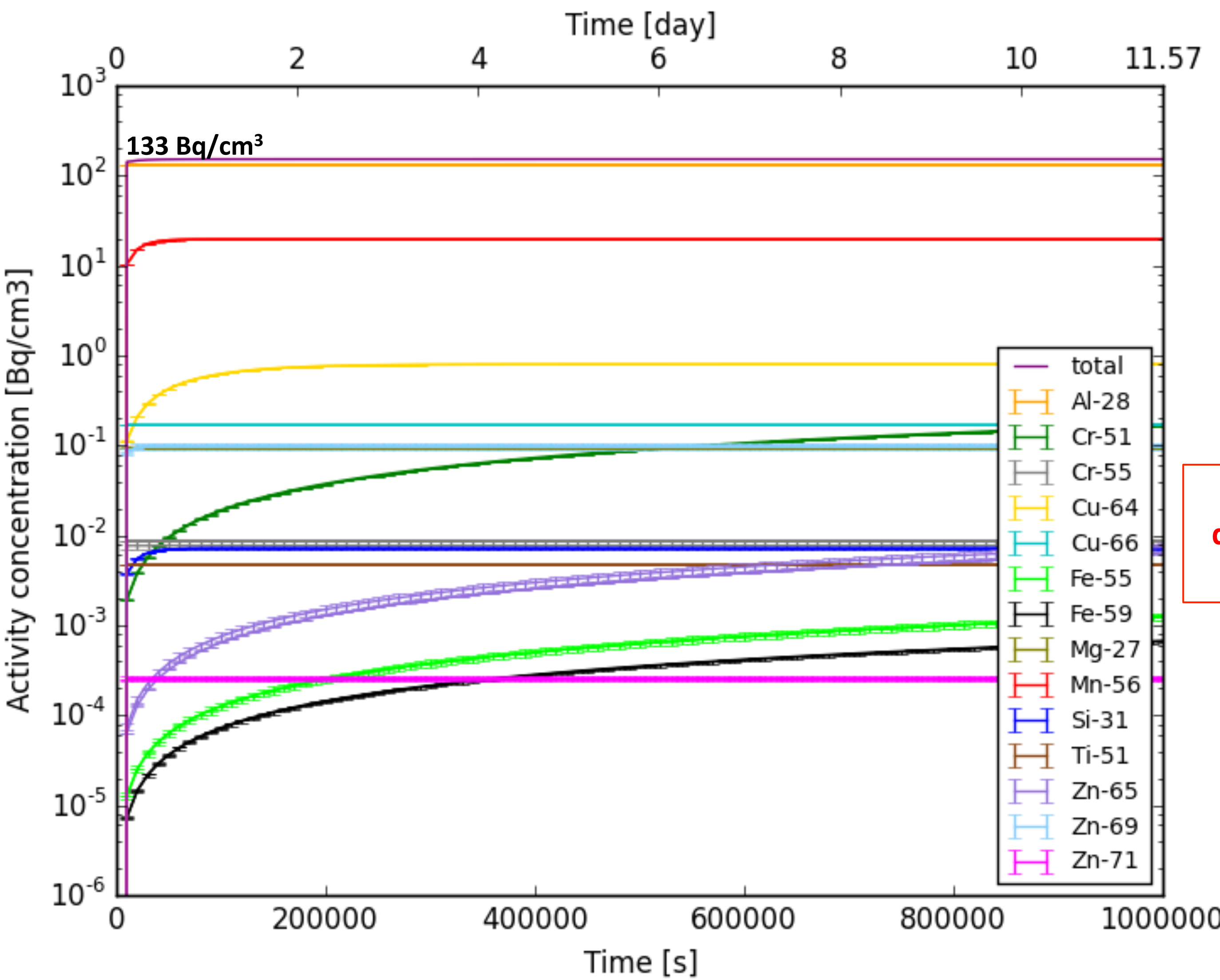


1.8 Å

Comparable prompt and decay gamma yield, mainly given by **Al** and **Mn**

Considerable decay gamma background during operation

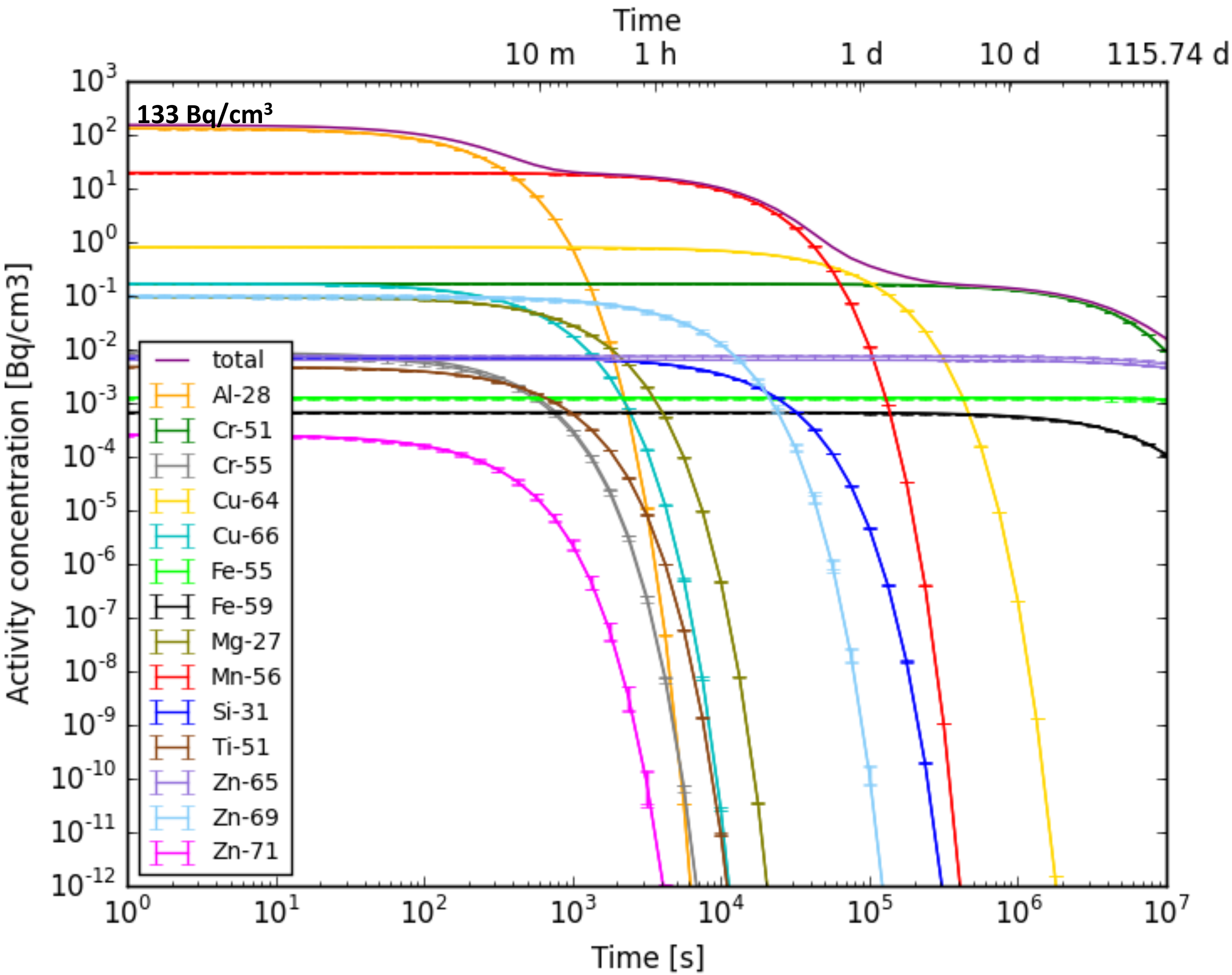
Activity build up in Al5754



^{28}Al and ^{56}Mn main contributors

Considerable decay gamma background during operation

Activity decay in Al5754



1/1000 activity with 1 day cooling

Summary

- Ar and aluminium activation can be an issue for neutron detectors, neutron activation has to be considered
- Simple and general MCNP6.1 model built for activation study
  - Proper cross section databases found
  - Analytical calculations can be replaced by simulation

Neutron induced gamma signal is negligible in terms of SBR

Negligible activity emission from continuous gas flow with 1 day storage

Prompt and decay gamma yields and activity are determined for the whole energy range and available in an easy-to-scale form

E. Dian et al.
Neutron activation and prompt gamma intensity in Ar/CO_2-filled neutron detectors at the European Spallation Source
arXiv:1701.08117 submitted to ARI

Thank you for your attention!