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

• $^3\text{He}$ replacement with $\text{B}_4\text{C}$-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

• 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

C. Rojas-Palma, et al., DOI: 10.1093/rpd/nch020
https://digital.library.unt.edu/ark:/67531/metadc678287/
Large area detectors at ESS with Ar/CO$_2$

- VOR, C-SPEC, T-REX @ ESS
  - Chopper spectrometers with large area detectors
  - Multi-Grid detector (*ILL/ESS/LU collaboration*): $^{10}$B$_4$C converter based detector with Ar/CO$_2$
  - Continuous counting gas flow

Large Ar/CO$_2$ counting gas volumes exposed to neutron radiation ($V \sim 5-10$ m$^3$)

A. Khaplanov et al.  
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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Assumptions and conditions

- Estimation of irradiating neutron flux
  - Various fluxes at sample position (VOR, T-REX, C-SPEC): conservative estimation: $10^{10}$ n/cm$^2$/s
  - 1-10% scattering on sample
  - 1 cm$^2$ sample surface
  - $R = 100$ cm smallest realistic sample-detector distance

10$^9$ n/s scattered neutron

10$^4$ n/cm$^2$/s scattered neutron flux at detector position

$10^4$ n/cm$^2$/s

10$^{10}$ n/cm$^2$/s

1 cm$^2$

R = 100 cm

10$^5$ cm$^2$ sphere surface

Standard operational conditions for ESS
Assumptions and conditions

- **Ar/CO₂** detector model for simulation and calculation:
  - 10 x 10 x 10 cm³ 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

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

- $r = 8.5 \text{ cm}$
- $d = 50 \text{ cm}$
- $r_v = 10 \text{ cm}$
- $a = 10 \text{ cm}$
Assumptions and conditions

**• Ar/CO\(_2\)** detector model for simulation and calculation:
  - 10 x 10 x 10 cm\(^3\) gas cube
  - 5 mm thick aluminum frame, Al5754 alloy
  - \(r = 8.5\) cm monoeinergetic pencil beam
    
    • 0.6, 1, 1.8, 2, 4, 5, 10 Å

**• \(t_{\text{irr}} = 10^6\) s** irradiation time
  (typical spallation source operation cycle)

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Assumptions and conditions

- $r = 8.5\, \text{cm}$
- $d = 50\, \text{cm}$
- $r_v = 10\, \text{cm}$
- $\Delta a = 0.5\, \text{cm}$
- $a = 10\, \text{cm}$
Assumptions and conditions

- Ar/CO\textsubscript{2} detector model for simulation and calculation:
  - 10 x 10 x 10 cm\textsuperscript{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

- \( t_{\text{irr}} = 10^6 \) s irradiation time
  (typical spallation source operation cycle)
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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/cm$^3$

low

1 detector volume/day: $V \sim 10$ m$^3$

1.28 x $10^6$ Bq/day
Activity decay in Ar/CO\textsubscript{2}

1.8 Å

Instant $^{41}$Ar background

$^{41}$Ar activity saturates at 128 mBq/cm\textsuperscript{3}

low

1 detector volume/day: $V \sim 10$ m\textsuperscript{3}

1.28 x $10^6$ 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

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

Considerable decay gamma background during operation

1.8 Å
Activity build up in Al5754

Considerable decay gamma background during operation

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

133 Bq/cm$^3$
Activity decay in Al5754

1/1000 activity with 1 day cooling
• 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

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

**Neutron induced gamma signal is negligible in terms of SBR**

**Negligible activity emission from continuous gas flow with 1 day storage**

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!