Estimation of ^{37}Ar activation and decay rate in DarkSide-50 experiment.

LIDINE 2023: LIght Detection In Noble Elements
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Iftikhar Ahmad

On behalf of DarkSide collaboration

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Introduction

- Rare event searches require ultra-low background conditions with both passive and active shielding.
- Transportation-induced activation adds radioisotopes, increasing background and limiting sensitivity.
- Future experiments like **DarkSide-20k** for **WIMP** searches use underground argon (**UAr**).
- Precise estimation of pre-installation induced radioactivity in UAr is essential.

Objective:

- Activation Calculation Software to estimate induced radioactivity during UAr **transportation**.
- Compare with DS-50's measured ^{37}Ar activity (**blind analysis**).
- The results are crucial as they can be used to validate cosmic activation estimates for future experiments.
- *The presentation is divided in two parts, the first part is **estimation** and the second part is **measurement**.*

Cosmogenic Estimation

- To estimate **^{37}Ar, ^{39}Ar, ^{42}Ar** and **^{3}H** activation yields in the UAr.
- **UAr** transport for DS-50:
    - Colorado (US) to LNGS (Italy) i.e by **shipping** and **aerial** transport.
- **^{37}Ar** is produced during transport and storage.
- **^{37}Ar** decays by electron capture and releases x-rays at **2.82 keV** (K-shell) and **0.27 keV** (L-shell).
- The DarkSide Collaboration has demonstrated the possibility to exploit the presence of a small contamination of **^{37}Ar ($t_{1/2}$=35.04 ± 0.04 days)** to calibrate at low energies.
- Activation calculation software tool named **COSAC** (COSmogenic Activation Calculation) developed by **Teena Vallivilayil John** (Ph.D. student at GSSI).

Radioactivity and induced activity

- The activation of radioisotopes (R) is the integral sum of **flux** and **reaction cross-section.**

$$R = N_t \int f(E).\sigma(E).dE$$

N_t = Number of target nuclei

f = Flux

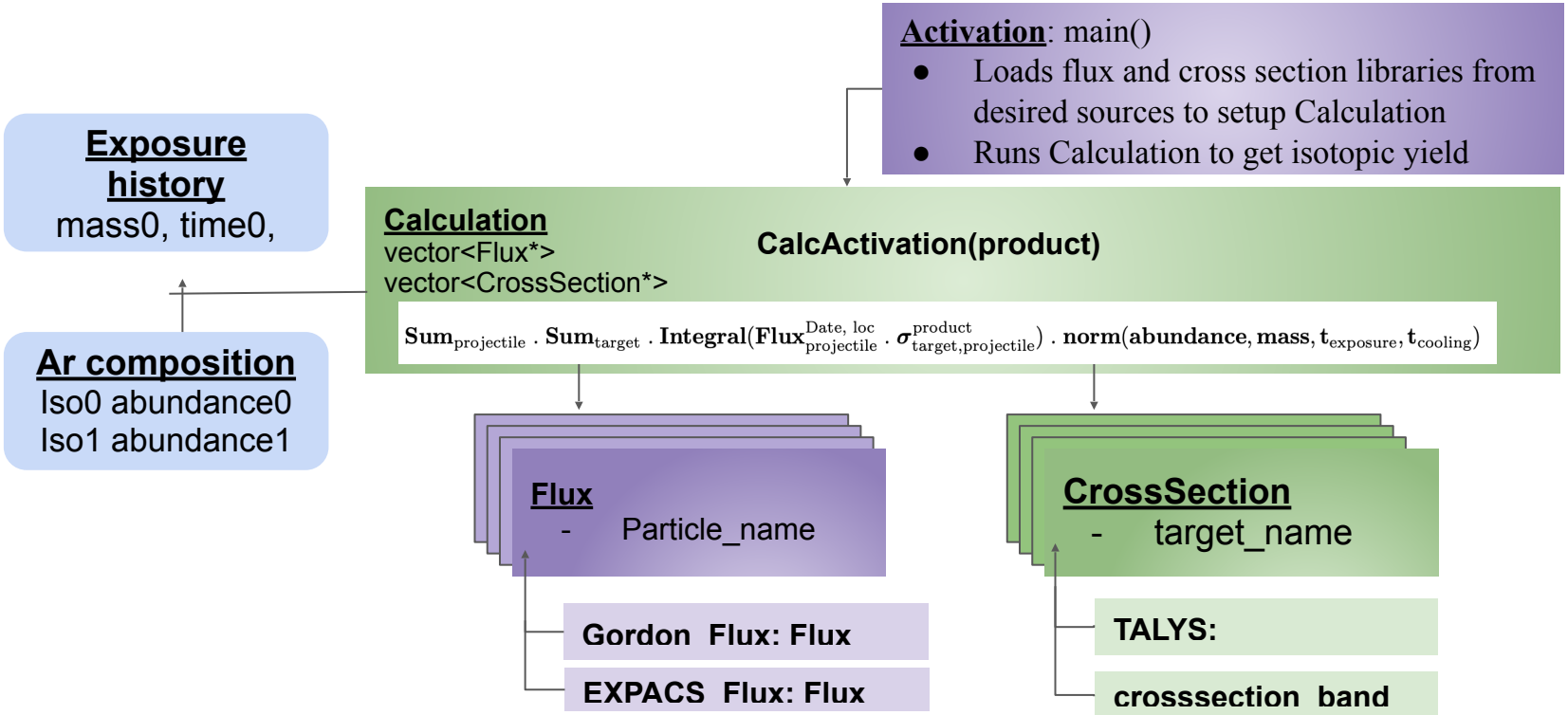
σ = Production cross section

- The induced activity (IA) is the number of decays of the radioisotope.

$$IA = R(1 - e^{-\lambda t_{\text{exp}}})e^{-\lambda t_{\text{cool}}}$$

t_{exp} is exposure time, representing UAr's fixed location exposure. t_{cool} is cooling time, denoting the duration between UAr exposure and detector activation.

COSAC outline

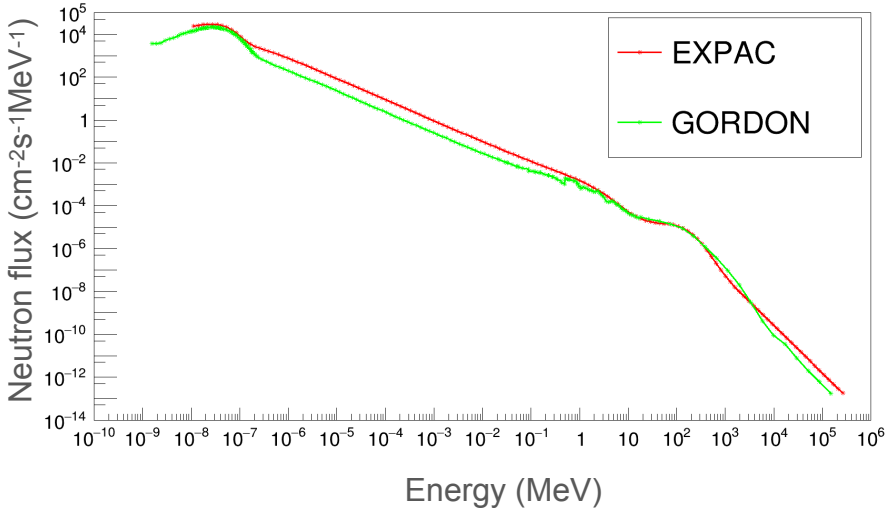


EXPAC and Gordon flux distribution

- Two flux estimation options: EXPAC simulation and Gordon model.
- EXPAC simulation estimates the flux based on the location and timestamp details.
- EXPAC based on PARMA model, covers various particles.
- Gordon model uses neutron flux data, extrapolates using location details.

Input parameters:

- Location (Latitude, Longitude, Altitude).
- Time.



Altitude=0.0°, Latitude=42.28°, Longitude=48.18°

Date: 14/01/2015

Cross-section data

Projectiles: **n, p, γ**
Targets: **^{36}Ar, ^{38}Ar, ^{40}Ar**

Major reaction channels

- ^{40}Ar (n,4n) ^{37}Ar
- ^{36}Ar (n,γ) ^{37}Ar
- ^{40}Ar (n,*) ^{3}H
- ^{36}Ar (n,*) ^{3}H
- ^{40}Ar (n,*) ^{3}H

Cross-section Libraries

Simulations Used

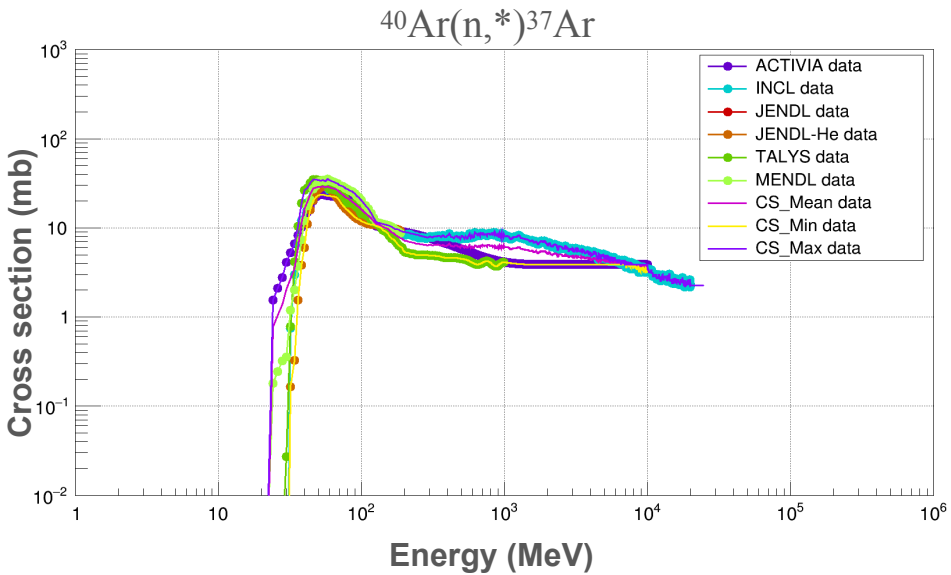
- ❑ TALYS
- ❑ ACTIVIA
- ❑ INCL

Databases Used

- ❑ JENDL-He
- ❑ EXFOR
- ❑ NNDC
- ❑ MENDL
- ❑ ENDF

Cross section Libraries

- The cross-section library is needed to calculate the activation.
- The reactions consider Argon isotopes as target, while neutron, proton, and photon as projectiles.
- The **CS_Mean data** (cross section mean) is used for determining the activity.
- **CS_Min** and **CS_Max** are minimum and maximum cross section at each energy point and are used to estimate uncertainty.

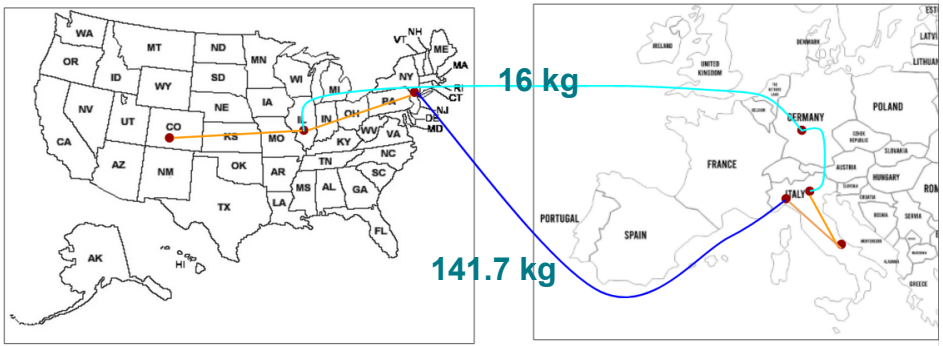


Cumulative induced activity of ^{37}Ar

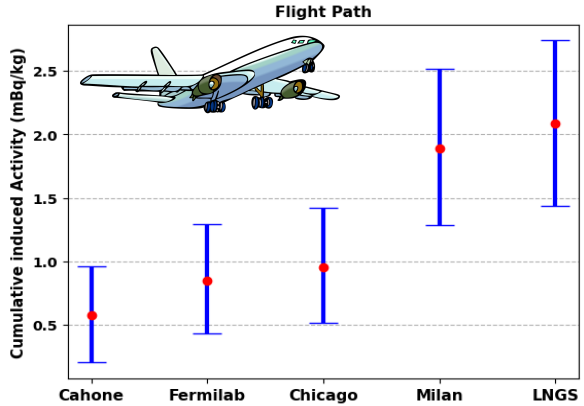
- **Two shipments**: ship and airplane.
- **Key locations:**

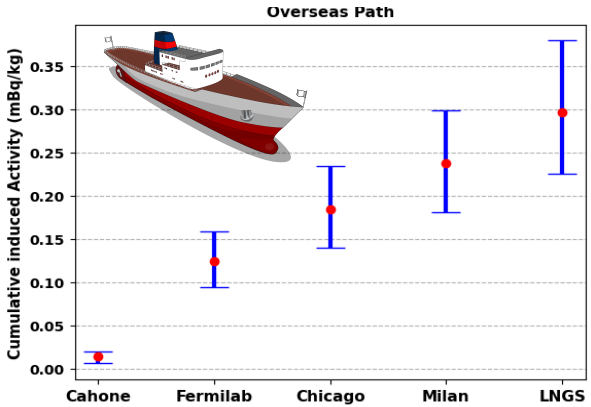
  Colorado, Fermilab, Chicago, Montreal, Genoa, Frankfurt, Milan, LNGS.
- **Detailed historical record:**

  latitude, longitude, altitude, entry/exit timestamps.
- Uncertainties in transportation paths and timings are considered.



Sketch of the path used for the DS-50 UAr





The error in the induced activity is the standard dev of flux, cross section and transportation at each location.

COSAC output

At 10-April-2015

Radioactive isotopes	UAr flown [mBq/kg]	UAr Shipped [mBq/kg]	Total Activity [mBq/kg]
^{37}Ar	$2.07^{+0.72}_{-0.66}$	$0.29^{+0.09}_{-0.08}$	$0.47^{+0.11}_{-0.10}$
^{39}Ar	$0.01^{+0.03}_{-0.03}$	$0.09^{+0.10}_{-0.07}$	$0.09^{+0.09}_{-0.06}$
^{42}Ar	$1.4^{+0.38}_{-0.39} \times 10^{-9}$	$4.0^{+0.47}_{-0.47} \times 10^{-9}$	$3.8^{+0.42}_{-0.42} \times 10^{-9}$
^{3}H	$0.10^{+0.04}_{-0.04}$	$0.28^{+0.09}_{-0.09}$	$0.26^{+0.08}_{-0.08}$

See talk by Valentina Cocco, Wednesday Afternoon (link).

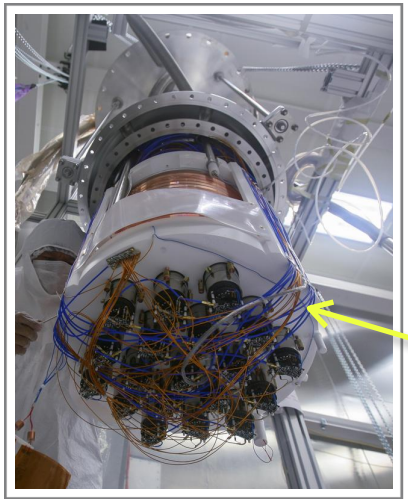
See talk by Susana Cebrián, Wednesday Afternoon (link).

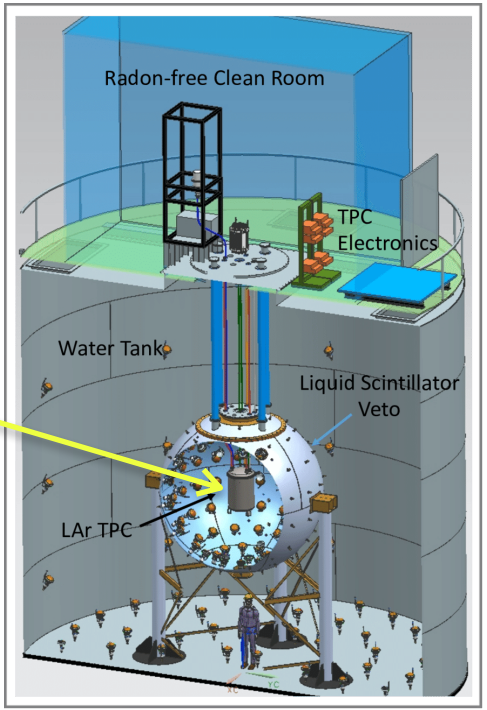
DarkSide-50 experiment

- The DS-50 experiment is based on a dual-phase Liquid Argon Time Projection Chamber (LAr-TPC).

- **LAr-TPC :**
  - Mass: **46.4 +/- 0.7 kg UAr**
  - 2013-2015 Atmospheric Argon
  - 2015-2018 Underground Argon

    (~1400 depletion factor regarding ^{39}**Ar** activity)
- **Liquid Scintillator Veto :**
  - Active and neutron detector (**30 ton**)
- **Water Tank :**
  - Active detector for muons (**1k-ton**)

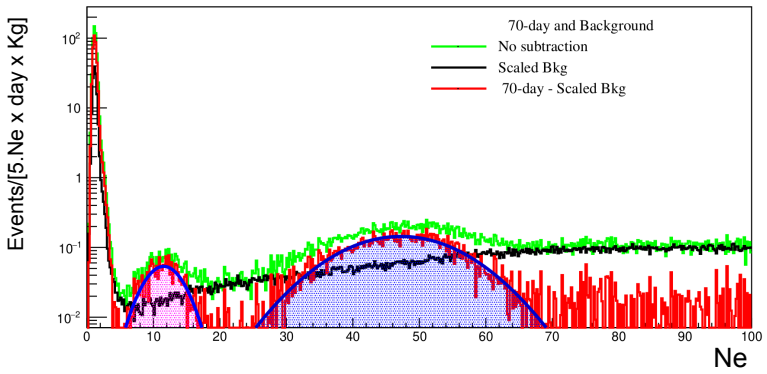




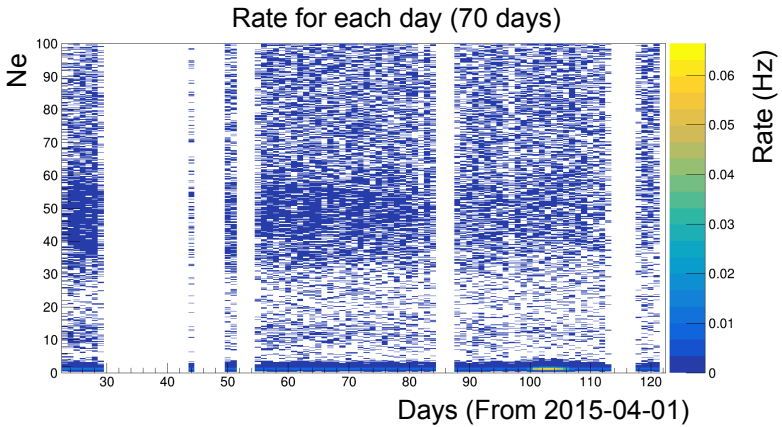
- **38** Photomultipliers tubes (PMTs), 19 at bottom and 19 on the top.

Stability of background

- Total mass of LAr in the TPC is 46.4 +/- 0.7 kg and cut acceptance due to fiducialization is **0.43**.
- The plot is scaled by livetimes for both **70-days data** and **500-days data.**
- Background is stable and we can subtract it from the 70-days data.
- By taking the slices of each day, we see the two peaks of ^{37}Ar.



The plot shows the y-projection of the 100-day (Green) and 100 days from 500-day data (Black). The red line shows the subtraction of background.



The plot shows the number of extracted electrons,Ne vs days, while the z-axis shows the Event rate/bin.

Activity of ^{37}Ar in DS-50

- Fitted simultaneously with one common parameter (τ) by the given function.

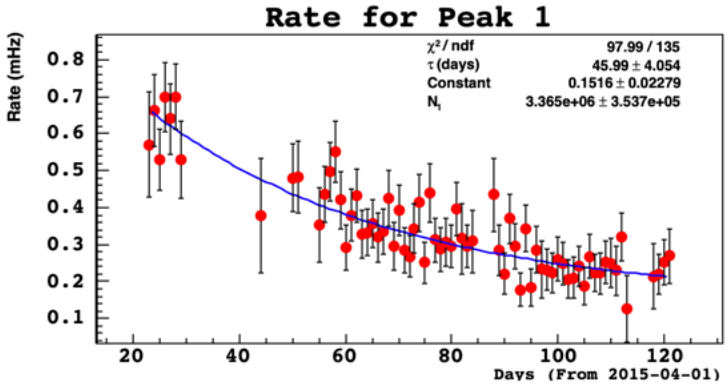
$$A(t) = \frac{N_{1,2}}{\tau} e^{-\frac{t}{\tau}} + C$$

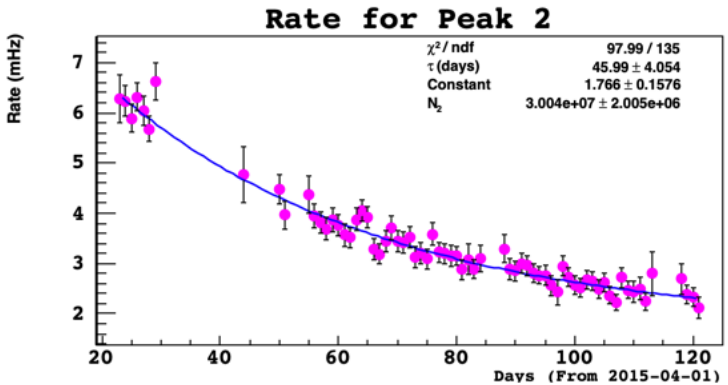
- The error bars are calculated by dividing the **sqrt(counts)/livetime.**

- A correction for **M-shell** is applied, as 1% of the activity is due to the M-shell capture.

^{37}Ar analysis from DS-50

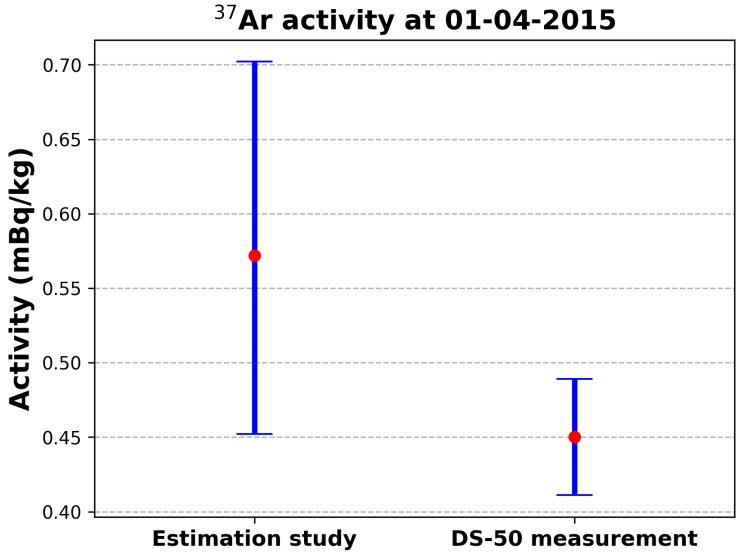
Branching Ratio L/K	0.09±0.03 [Philos Mag. 475–482, (1962); Phys. At. Nucl. 70,300–310 (2007); Phys. Rev.120:2196–2200, (1960)]
Activity [L+K] (mBq/kg)	0.44±0.039
Activity [L+K+M] (mBq/kg)	0.45±0.039
Parts per billion (10^{-14})	3.27±0.27





Activation and measurement comparison

- The activity from the estimated activation and the measurement from DS-50 agrees within **one sigma**.
- The activity for estimation study is converted to 01-04-2015 from 10-04-2015.
- Validate the results with DS-50 data with ^{37}**Ar** (**Blind Analysis**).
- The DS-50 measurement study included the branching ratio (L/K) of ^{37}**Ar** which agrees with other experimental values by **one sigma**.



Conclusion

- Utilised Activation Calculation Software to estimate induced activity of ^{37}**Ar** isotope in **UAr**.
- The activity from the estimated activation and the measurement from **DS-50** agrees within **one sigma**.
- The results are important as they can be used to validate cosmic activation estimates for future experiments.
- The alignment between the **estimated** and **experimental** measurement of ^{37}**Ar** activity validates the reliability of our approaches.

Thank you for your attention