DarkSide Materials Weekly Meeting:
Update on Ar activation

Goal: to update the first estimates of cosmogenic activation on **Argon,** mainly of ^{39}**Ar**:

- Including a more realistic exposure history during Ar storage and transportation.
- Considering production by sources other than cosmic neutrons.

- Production rates at sea level
- Correction factors for cosmic ray fluxes
- Exposure history
- Results for activity

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Production rates

^{39}Ar production rates in Ar precisely determined with neutron beam which mimics cosmic spectrum at Los Alamos and estimates for muons, protons and cosmic gamma rays at sea level.

R. Saldanha et al, Phys. Rev. C 100 (2019) 024608

TABLE V. Total cosmogenic production rates of ^{39}Ar at sea level. The first row is the estimate from fast neutrons based on the measurement presented in this work, while the other rows are best estimates made from existing experimental data and models.

Reaction	Estimated ^{39}Ar production rate [atoms/(kg$_{Ar}$ day)]	Fraction of total AAr (%)
^{40}Ar (n, 2n)^{39}Ar+ ^{40}Ar(n, d)^{39}Cl	759 ± 128	72.3
^{40}Ar (μ, n)^{39}Cl	172 ± 26	16.4
^{40}Ar (γ, n)^{39}Ar	89 ± 19	8.5
^{40}Ar (γ, p)^{39}Cl	23.8 ± 8.7	2.3
^{40}Ar (p, 2p)^{39}Cl	<0.1	<0.01
^{40}Ar (p, pn)^{39}Ar	3.6 ± 2.2	0.3
^{38}Ar(n, γ)^{39}Ar	≪ 0.1 (UAr)	–
	1.1 ± 0.3 (AAr)	0.1
Total	1048 ± 133	100

In very good agreement with estimated production rate from comic neutron spectrum and selections of production cross sections

Rate	^{39}Ar
kg^{-1} d^{-1}	725 ± 79

Correction factors

Exposure to cosmic rays will happen at different altitudes and latitudes
→ correction factors are needed to the assumed cosmic rays fluxes at sea level, different for different components

J.F. Ziegler, Terrestrial cosmic ray intensities, IBM J. Res. Develop. 42 (1998) 117.

- **Protons, muons**

$$I_2 = I_1 \exp\left(\frac{A_1 - A_2}{L}\right),$$

where I_1 is the cascade flux at some altitude (pressure) and I_2 is the flux at altitude A_2, both altitudes being expressed in g/cm^2.

Table 3. Sea-level particle absorption lengths.

Particle	Length L (g/cm^2)
Electrons	100
Protons	110
Pions	113
Neutrons	136
Muons and muon capture	261

Location	H (ft)	A (g/cm2)	I ratio Cortez mu	I ratio Cortez p
Cortez (1887 m)	6191	823.480	**2.23**	**6.72**
New York	0	1033.000		

- **Neutrons** Extrapolation for Colorado location of deduced factors f due to altitude and geomagnetic rigidity at Denver and Leadville.

Location	H (ft)	A (g/cm2)	f	I ratio DS	f at DS	I ratio Cortez	f at Cortez
Denver	5280	852.262	4.11	0.673	6.1	0.809	5.1
Leadville	10200	705.225	12.86	1.985	6.5	2.386	5.4
DarkSide (2134 m)	7001	798.483			**6.3**		**5.2**
Cortez (1887 m)	6191	823.480					

Exposure history

- More realistic exposure conditions needed: fixing tentative **exposure times** and **places (altitude)** for shipping: URANIA → ARIA → LNGS

  - **Storage of UAr at Urania**

" It will take approximately 8 days to fill 1 skid with 1999 kg of argon. A container from Urania can hold 3 skids. So total time on surface at Urania for 1st skid is approx. 24-30 days until a truck shows up to take all 3 skids to Houston."

  - **Trip from Urania to a shipping port**

"7 days to Houston"

  - **Trip overseas to Europe**

"Trip to Cagliari : 60 days at sea. Clear customs and trip to Aria: minimum 7 days, maybe more depending on Customs"

  - **Processing and storage of UAr at Aria**

"3 skids should arrive at Aria every 3 weeks once the process gets going. I don't know if Aria wants to wait for all skids to arrive before processing starts or process as they arrive"

  - **Trip from Aria to LNGS**

"14 to 21 days."

  - **Storage at LNGS**

"If everything is ready for the arrival of the sk
underground as they arrive."

Urania exposure (d)	10	20	30
US trip exposure (d)	7		
Overseas trip exposure (d)	67		
Aria decay time (d)	0		
Itay trip exposure (d)	20		

Results

Induced activity *A* knowing the exposure history to cosmic rays at each step

$$A = R\left[1 - \exp(-\lambda t_{exp})\right] \exp(-\lambda t_{cool})$$

t_{exp} = exposure time

t_{cool} = cooling time

- Urania exposure: including correction factor for Cortez altitude; each third of Ar with different exposure time
- US trip exposure: average between maximal (from Cortez altitude) and minimal (sea level)
- Overseas and Italy exposure: at sea level
- No exposure assumed for Aria yet

				Urania		US		Overseas		Italy		Total	
	R	err	f Cortez	A	err	A	err	A	err	A	err	**A**	**err**
	(kg-1 d-1)			(kg-1 d-1)		(kg-1 d-1)		(kg-1 d-1)		(kg-1 d-1)		**(kg-1 d-1)**	
n	759	128	5.23	0.561	0.095	0.117	0.020	0.359	0.061	0.107	0.018	**1.143**	**0.115**
mu	172	26	2.23	0.054	0.008	0.014	0.002	0.081	0.012	0.024	0.004	**0.173**	**0.015**
p	3.6	2.2	6.72	0.003	0.002	0.001	0.000	0.002	0.001	0.001	0.000	**0.006**	**0.002**
g	112.8	20.9	1	0.016	0.003	0.006	0.001	0.053	0.010	0.016	0.003	**0.091**	**0.011**
total				**0.634**	**0.095**	**0.137**	**0.020**	**0.495**	**0.063**	**0.148**	**0.019**	**1.414**	**0.117**
(%)				44.8		9.7		35.0		10.5			

A (mBq/kg)	**err**
0.0164	**0.0014**

Largest activation from Urania exposure and the overseas trip

Results

- Comparison to the very first estimate of induced ^{39}**Ar** activity:

A (mBq/kg)	err
0.0164	0.0014

R (kg-1 d-1)		Exposure	A (mBq/kg)	
1048	126	35 d Colorado + 41 d sea level	0.022	0.003

→ the residual level (at 2-3% of quantified activity in DS50, 0.73 mBq/kg) could be confirmed.

- Questions to be clarified to complete the study:
  - *Urania:* altitude of facilities in Cortez?
  - *Urania:* storage of UAr is made at surface when being extracted?
  - *Aria:* total time spent there for UAr? Depth when being stored after/before processing?