THE DARKSIDE-20k UNDERGROUND ARGON PROCUREMENT CHAIN

LIDINE 2023: LIght Detection In Noble Elements

September 20, 2023

Madrid

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On behalf of the Darkside Collaboration

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ARGON

Large liquid argon detectors offer one of the best avenues for detecting galactic Weakly Interacting Massive Particles (WIMPs) via their scattering on atomic nuclei.

However, Atmospheric Argon (AAr) has a naturally occurring radioactive isotope ^{39}Ar,

- isotopic abundance of 8×10^{-16} in mass,
- is a β-emitter of cosmogenic origin,
- activity ~ 1Bq / kg,
- $T_{1/2}$ = 269y.

Isotope	Abundance	Specific activity (Bq/kg_{Ar})
^{40}Ar	0.9960	Stable
^{36}Ar	0.0033	Stable
^{38}Ar	0.0006	Stable
^{39}Ar	8.2×10^{-16}	1.0 [7,8]
^{37}Ar	$\approx 1.3 \times 10^{-20}$	$\approx 4.5 \times 10^{-2}$ [9]
^{42}Ar	6.8×10^{-21}	6.8×10^{-5} [10,11]

PHYSICAL REVIEW C 100, 024608 (2019)

UNDERGROUND ARGON (UAr)

- The activation of materials due to exposure to cosmic rays may become an important background source for experiments investigating rare event phenomena.
- Dark matter experiments require ultra-low background conditions.
- In this context, long-lived radioactive isotopes induced in the materials of the experiment by the exposure to cosmic rays during fabrication, transport and storage can be relevant.

UAr CHAIN

1st → URANIA

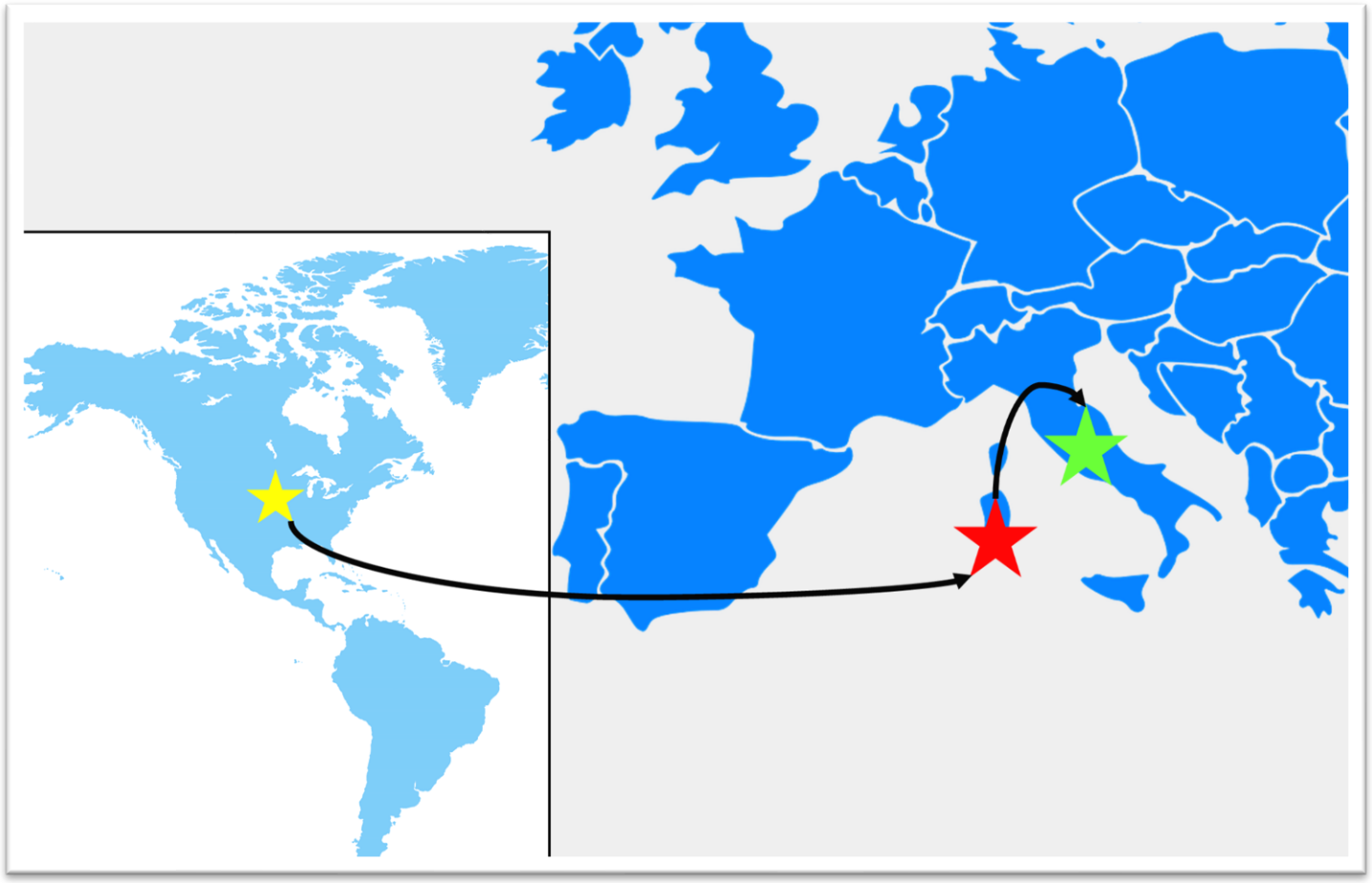
Doe Canyon, Colorado USA

2nd → ARIA

Sardinia, Italy

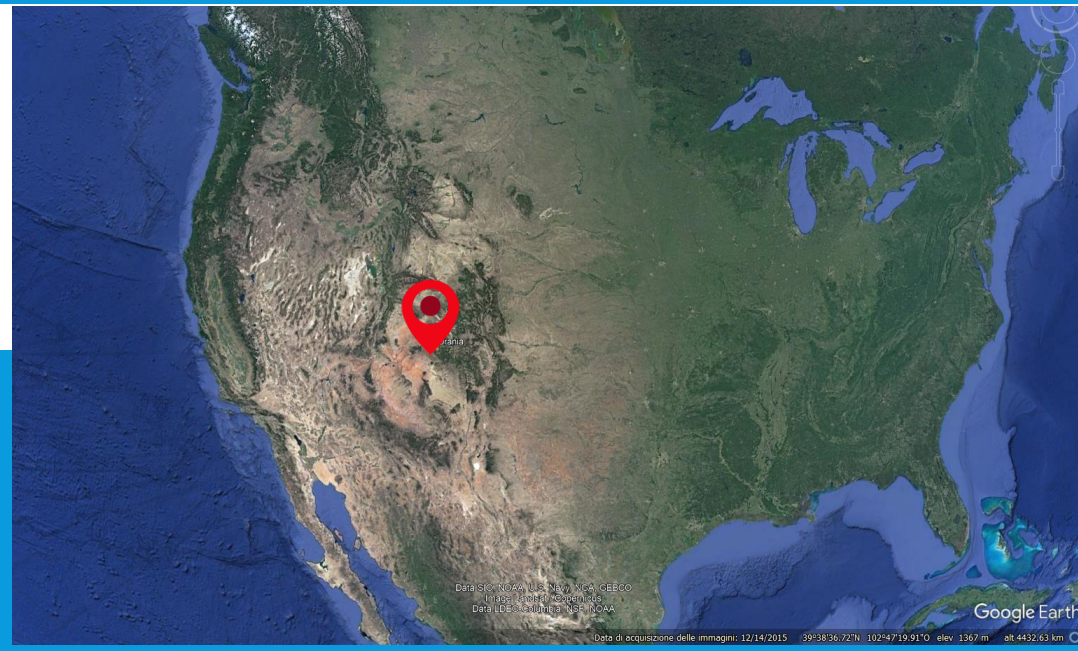
3rd → DarkSide-20k

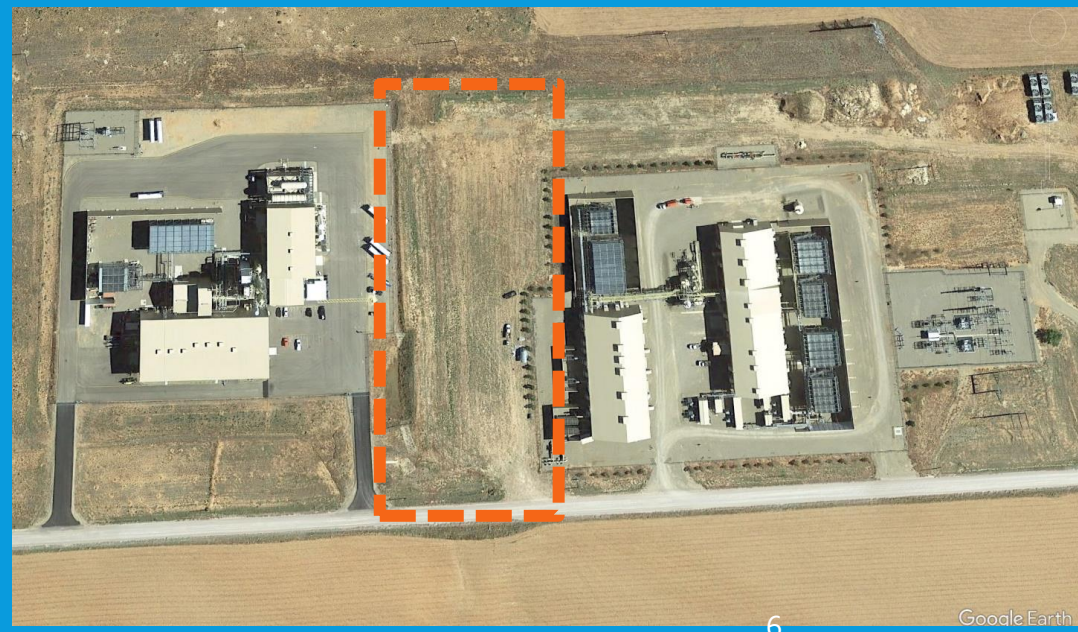
Laboratori Nazionali del Gran Sasso (LNGS), Italy



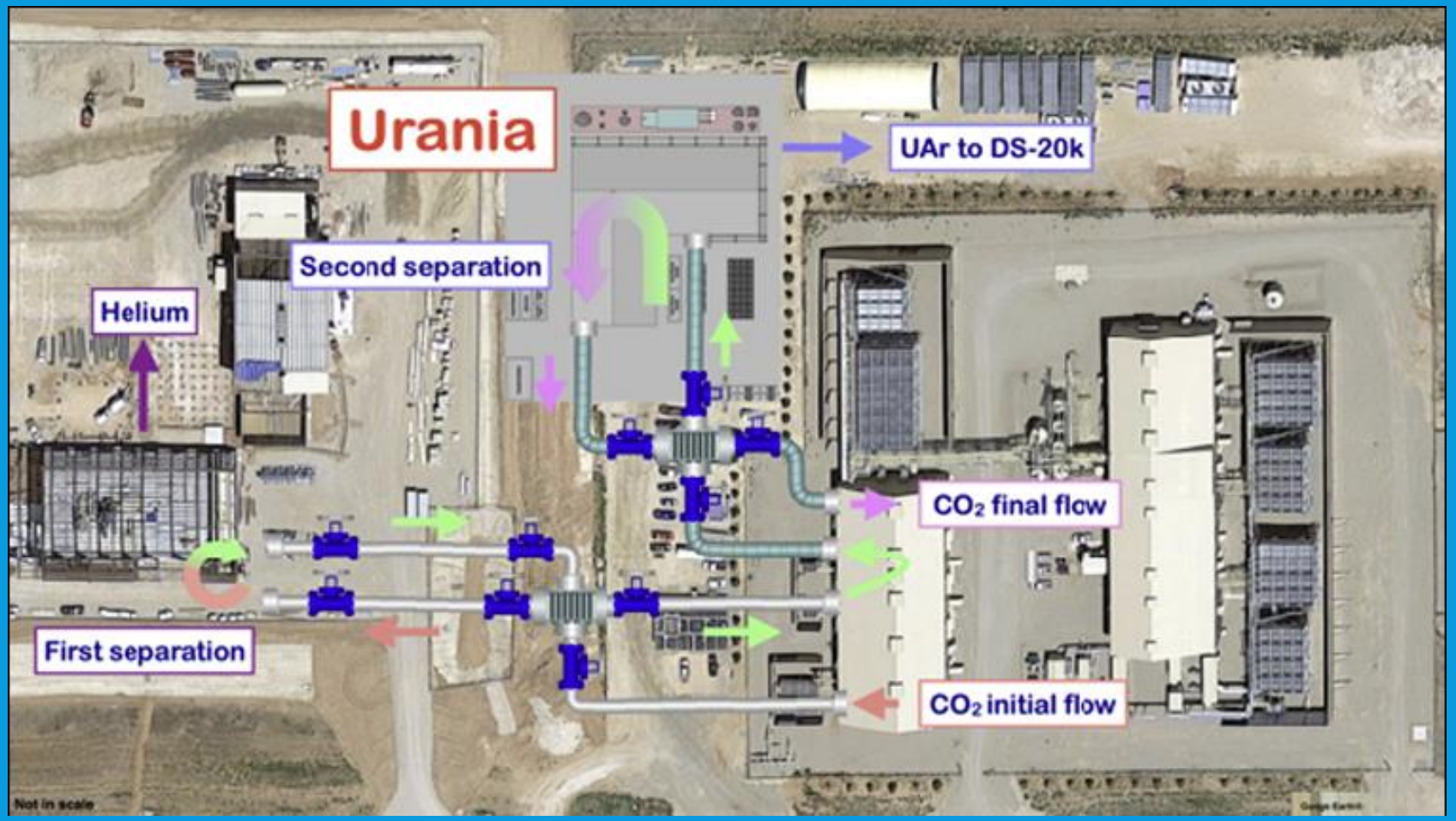
UAr – PRODUCTION SITE

- Doe Canyon, Dolores County, SW Colorado
- Doe Canyon is a natural carbon source field. It is placed near one of the most prolific natural CO_2 source fields in the world
- Kinder Morgan (KM) operates the Doe Canyon Deep unit. They produce CO_2 that is used for oil drilling in New Mexico and Texas
- The CO_2 source field is several hundred meters underground, so it has been protected by cosmic ray





URANIA FACILITY



CO_2

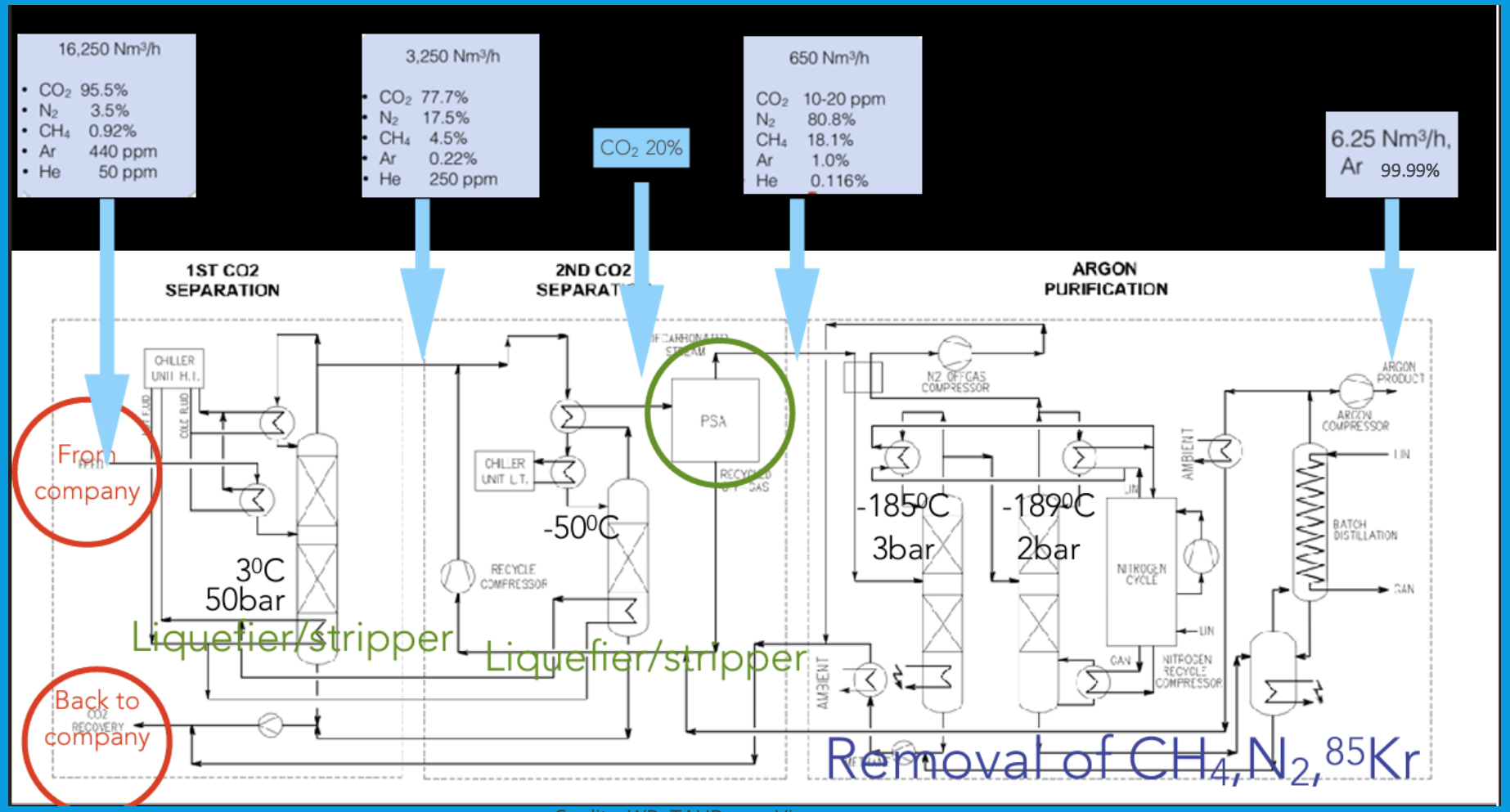
URANIA

CO_2

UAr

Credits: Federico Gabriele

URANIA FACILITY



- UAr production = **250 kg/d**
- MAX UAr prod. = 330 kg/d
- UAr purity = **99.99%**

For the DS-20k experiment a higher level of purity is required

Credits: WB, TAUP 2023 Vienna

SOME PICTURES

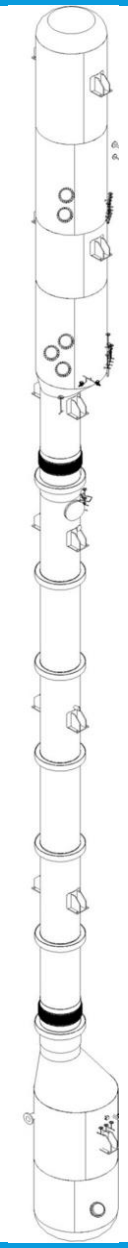
Credits: Marino Simeone & Federico Gabriele

SOME PICTURES

Credits Federico Gabriele & Andrew Renshaw previous talks

SOME PICTURES

Credits: Andrew Renshaw previous talks



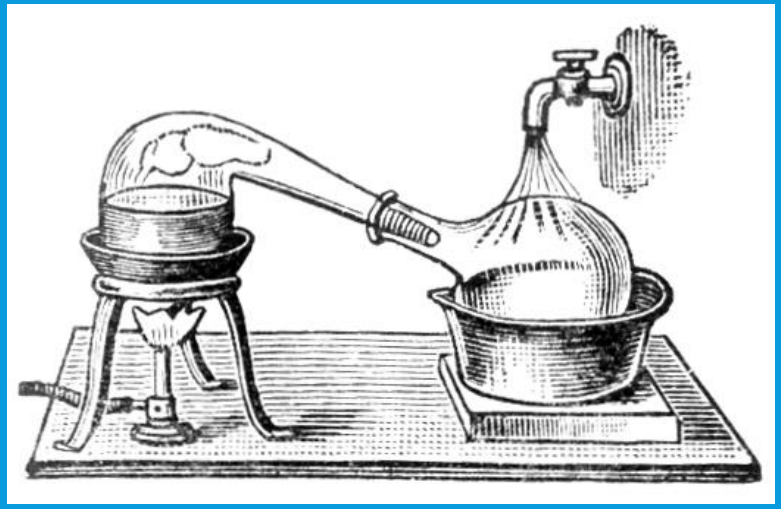
ARIA

WHAT IS ARIA?

ARIA is a **CRYOGENIC DISTILLATION COLUMN**

ARIA IS A CRYOGENIC **DISTILLATION COLUMN**

CONDENSER



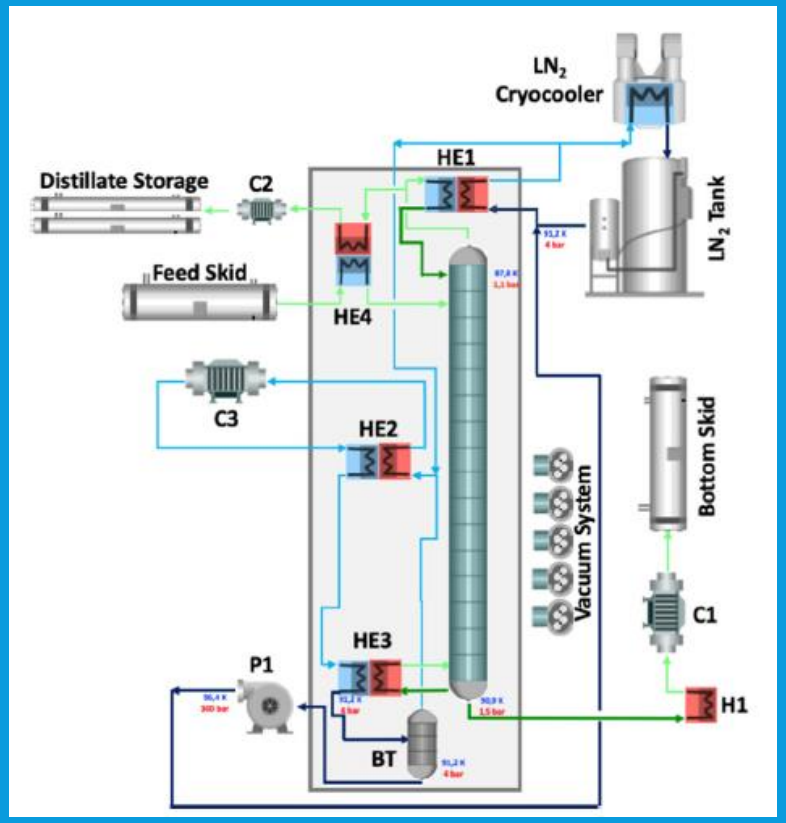
REBOILER

Distillation separates different components from a fluid based on their **different boiling points**.

In the specific case of isotopic distillation, the elements we try to separate are isotopes, so the difference in volatility is very small! And it makes the process harder!

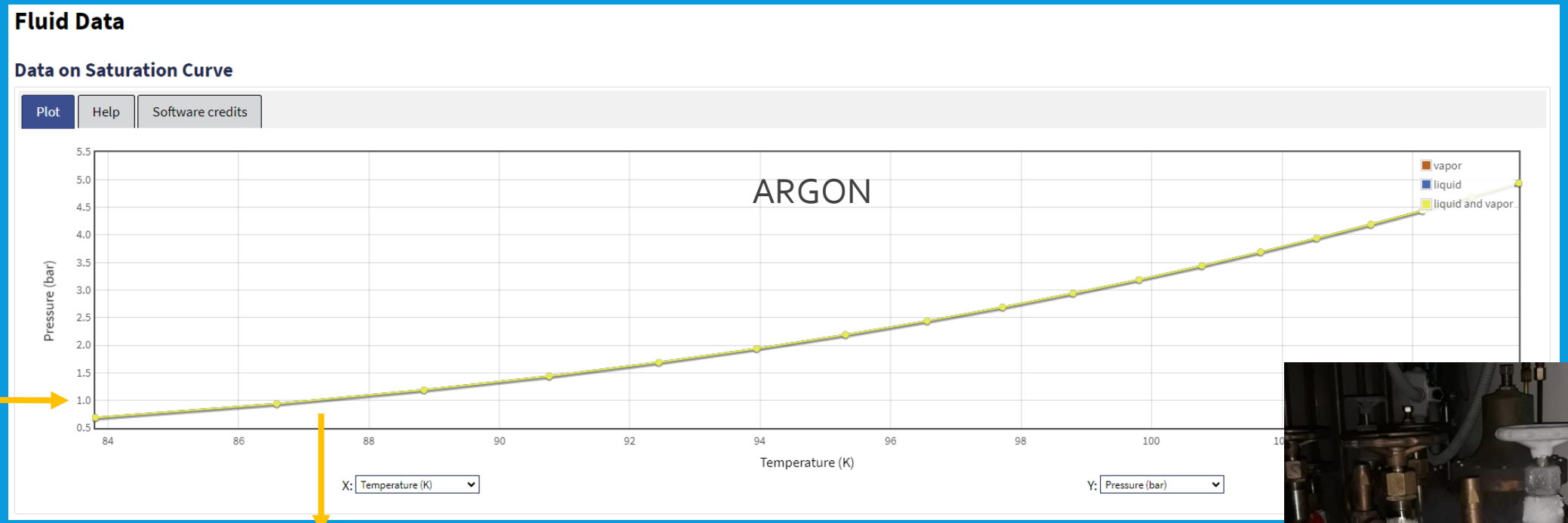
For this process, the liquid and gaseous phases of the fluid must coexist.

ARIA IS A CRYOGENIC **DISTILLATION COLUMN**



Credits: Federico Gabriele

ARIA IS A **CRYOGENIC** DISTILLATION COLUMN

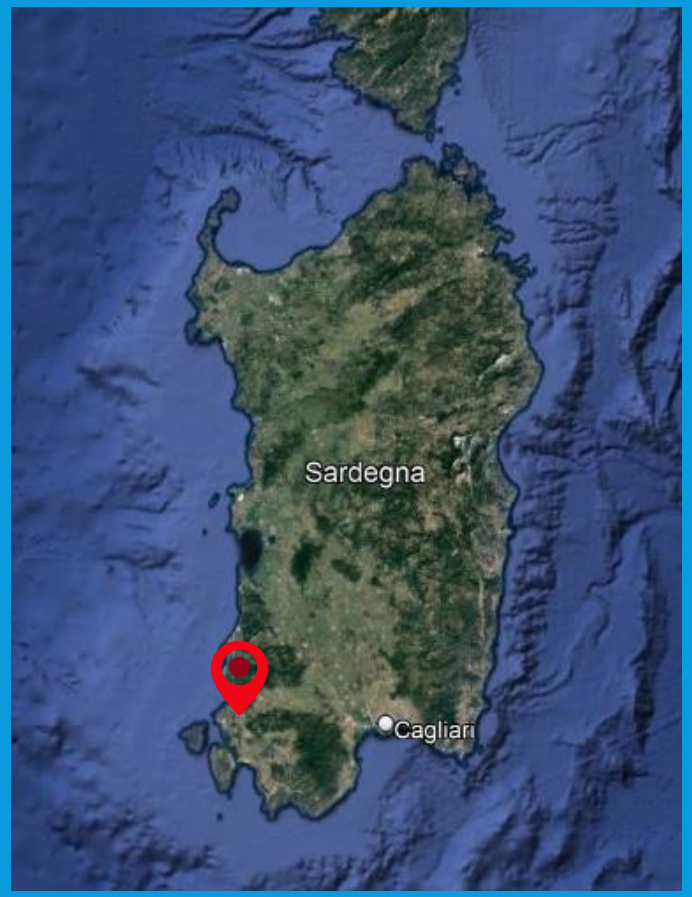


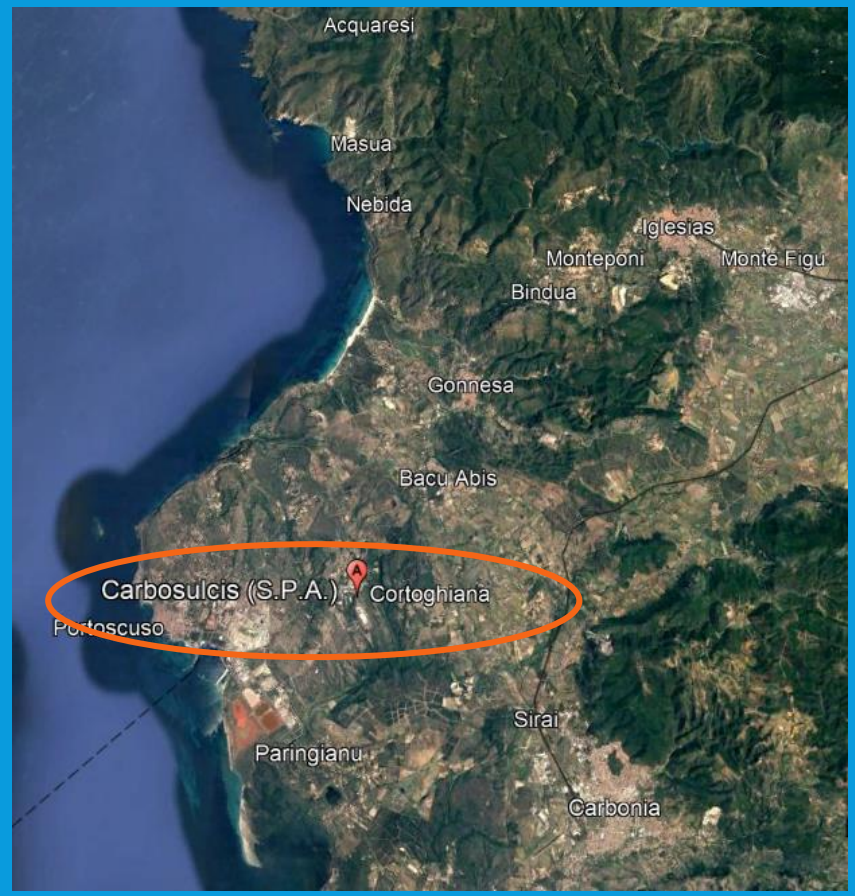
1bar

~ 87K

Credits: https://webbook.nist.gov/

WHERE IS ARIA?



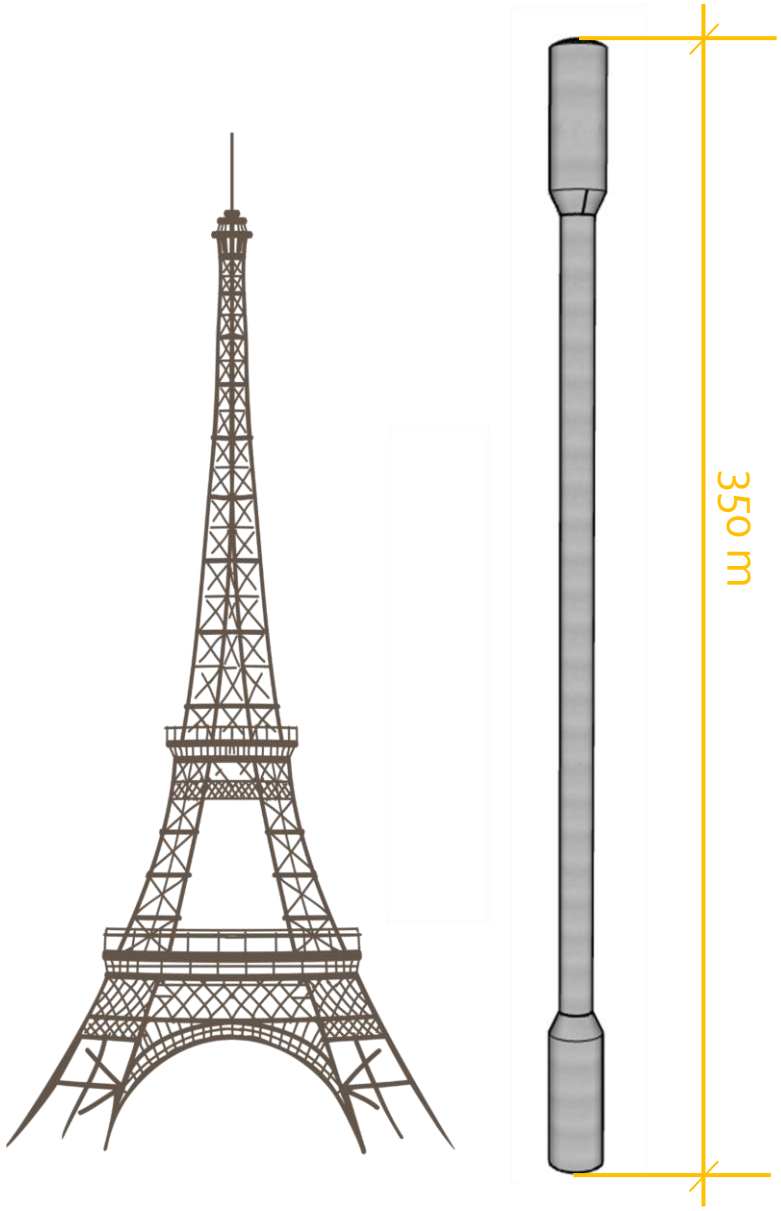


CARBOSULCIS

CARBOSULCIS – some info

- Carbosulcis is the last **coal mine** in Italy
- Dec. 2018 → Carbosulcis stopped coal production
- Access to the mine is guaranteed by 4 shafts and 1 underground road
- One of these **deep shafts (Seruci)** is going to host ARIA

Credits: Carbosulcis spa



$$ln\alpha_{i-j} \cong ln\frac{P_i}{P_j}$$

$$S_{i-j}^{T\,B} = (\alpha_{i-j})^{N}$$

WHY DOES ARIA "NEED" CARBOSULCIS' SHAFT?

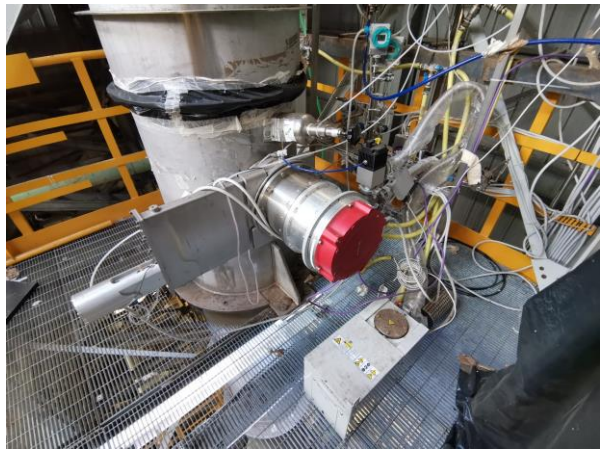
When the **boiling points** of the substances that we want to distil are very close, we need a massive number of **theoretical stages**.

$N_{(ARIA)}$ = 2870 stages → tot. active height = 287 m → tot. column height = 350m

For more details see: Eur. Phys. J. C (2021) 81:359

ARIA COLUMN - some numbers

- Height: 350 m
- External diameter: 71 cm
- Internal diameter: 32 cm
- Tot. weight: 100 ton
- 1 top module
- 1 bottom module
- 28 central modules
- 2 LN pumps (+ 2 backup)
- 4 Stirling cryogenerators
- 1 GN compressor (+1 backup)
- 5 vacuum stations



SERUCI MINE SHAFT

- Depth 350 m
- Diameter 5 m
- Shaft lining ~ 40 cm
- Year of construction 1940s
- Bottom shaft -200 m AMSL

Credits: Carbosulcis spa

PRELIMINARY WORK

DONE

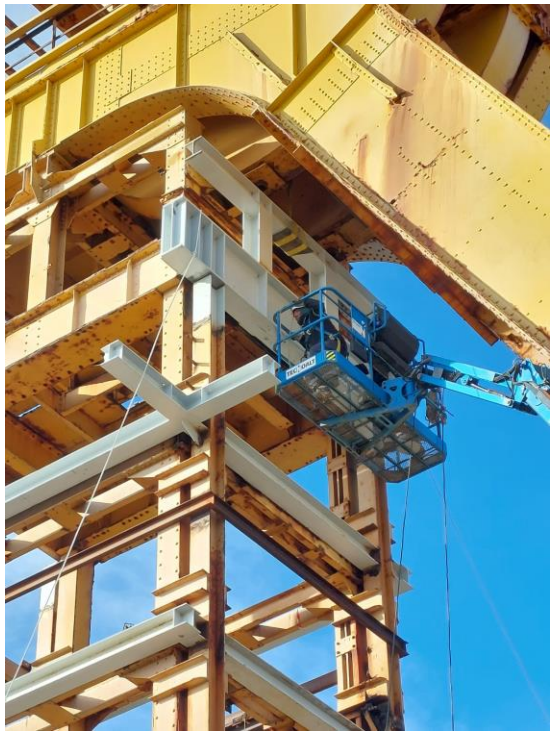
1. **Inside the shaft**: Dismantling the old pipes, electrical cables and obsolete facilities. Refurbishment of the wood beams and their anchors.

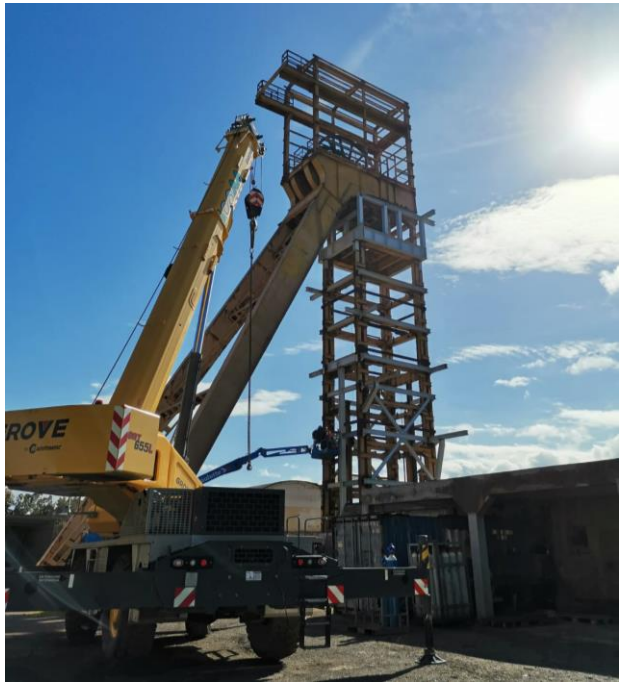
PRELIMINARY WORK

IN PROGRESS

2. **Outside of the shaft**:

Refurbishment of the headframe



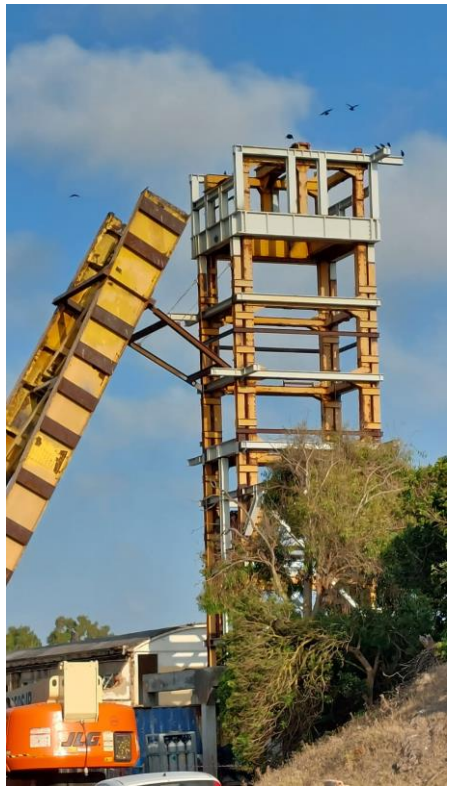


PRELIMINARY WORK

IN PROGRESS

2. Outside of the shaft:

Refurbishment of the headframe

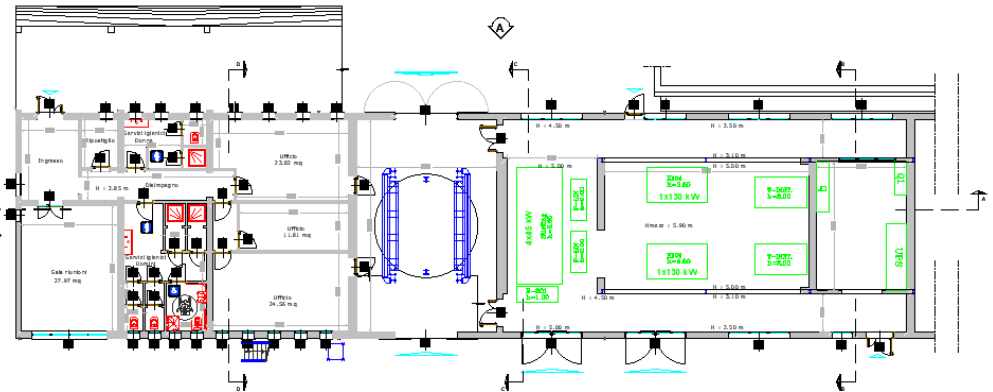


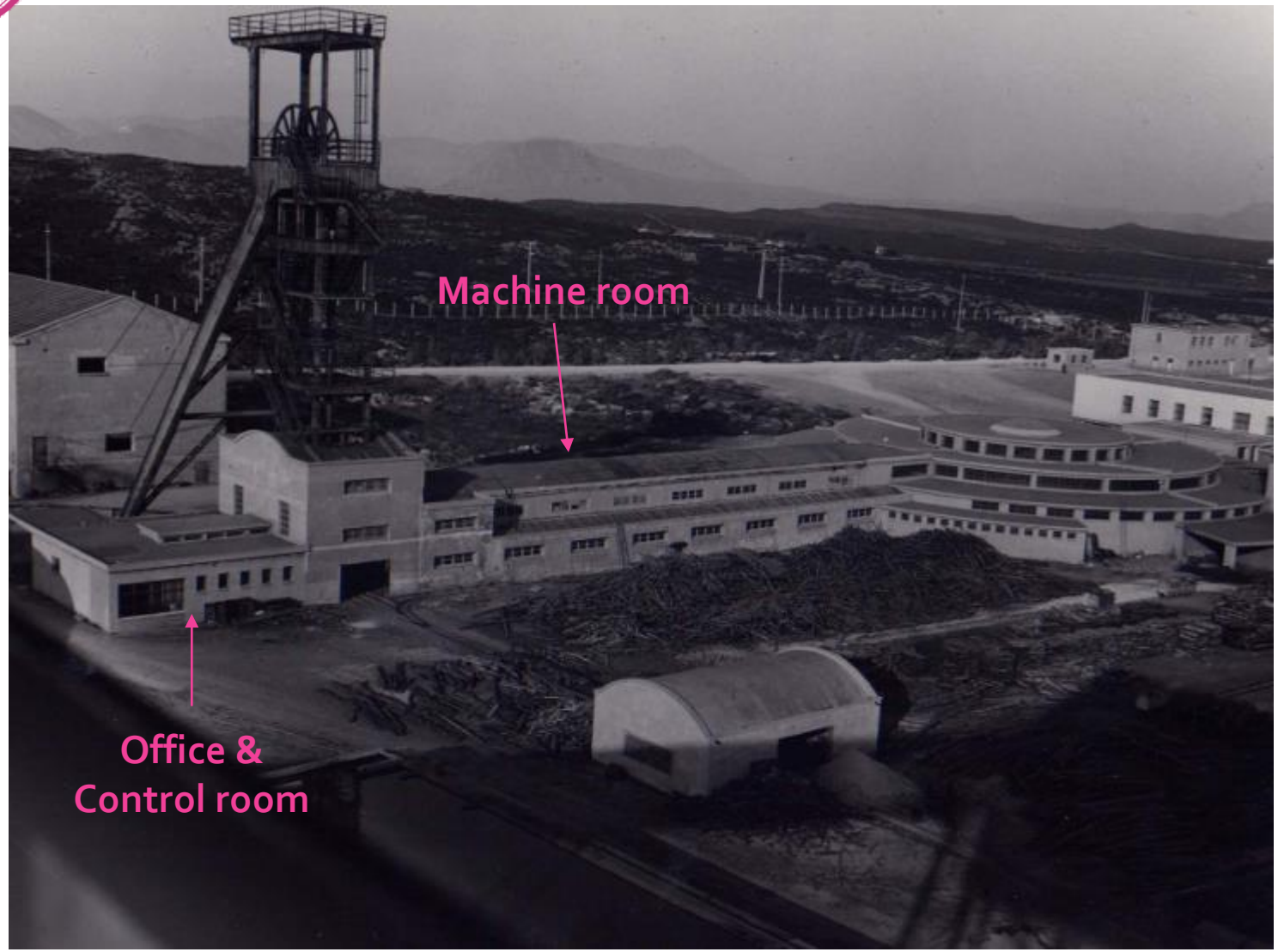
PRELIMINARY WORK

IN PROGRESS

2. **Outside of the shaft**:

   Civil work, refurbishment of the building



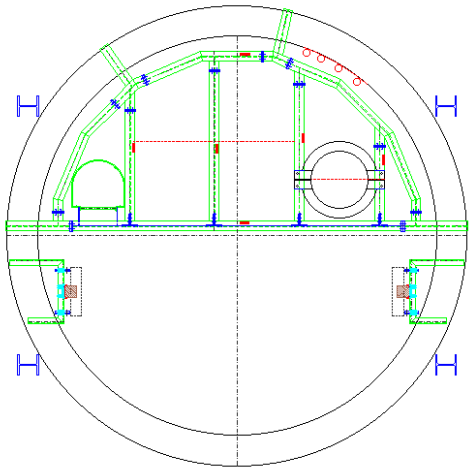


COLUMN INSTALLATION

PENDING

- ✓ Design of the support structure
- Installation of the beams
- Installation of the fiberglass grid

Up to now
23 platforms out of 87
have already been installed



Credits: Carbosulcis spa

MODULE PLACEMENT – 1st test

DONE

March 15, 2021

A lot of work has been done together with Carbosulcis for carrying out this crucial test.

The module was lifted down for some meters inside the shaft.

Each module has:
- high 12 m
- diameter 70 cm
- weight 3000 kg
- held by 3 support structures

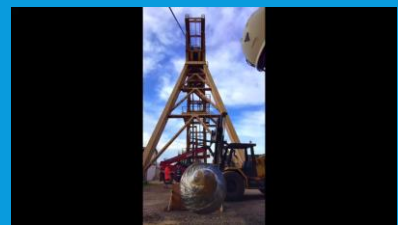
MODULE PLACEMENT – 1st test

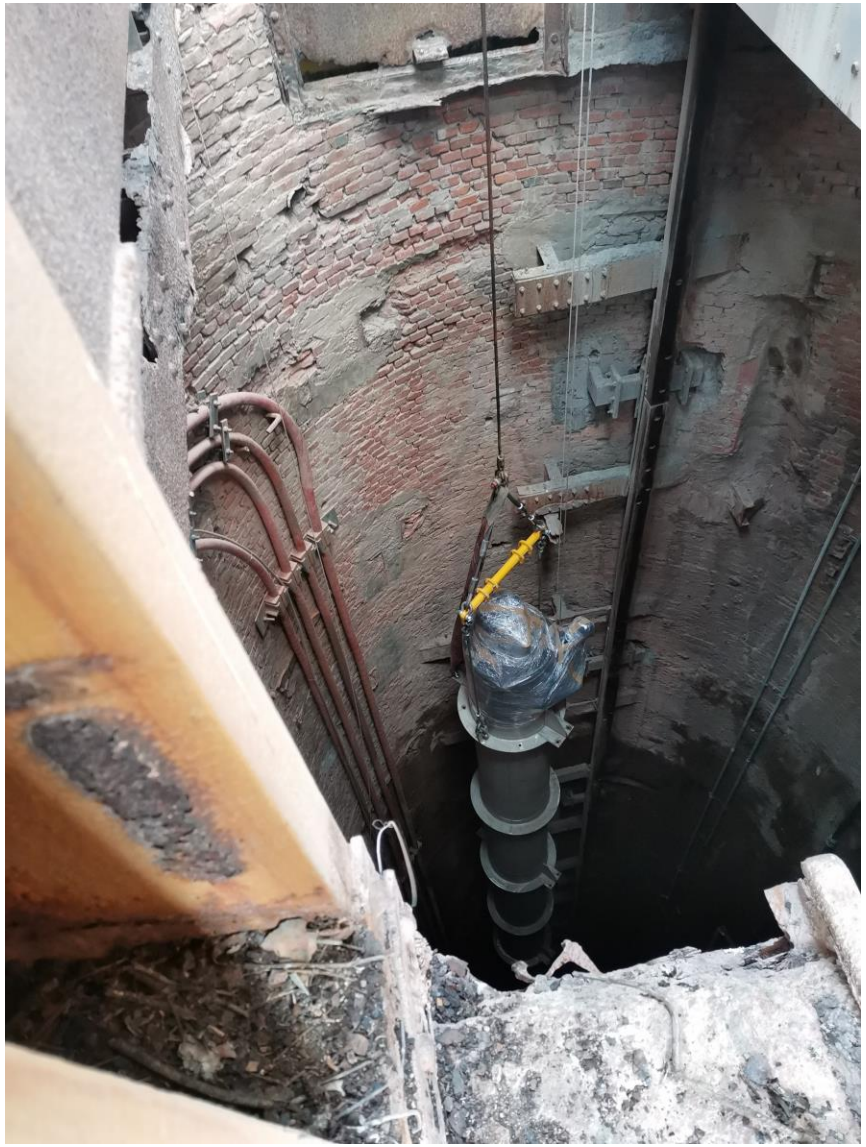
DONE

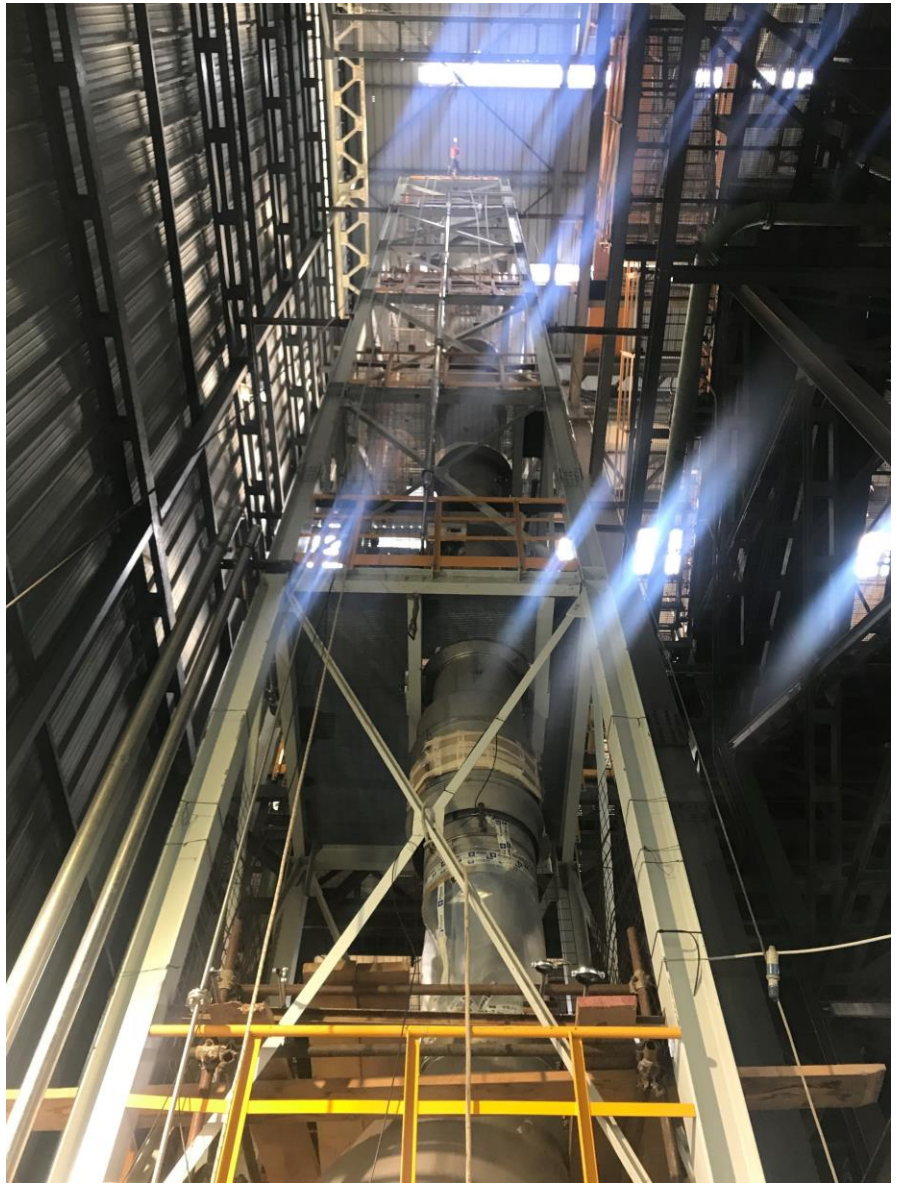
March 15, 2021

A lot of work has been done together with Carbosulcis for carrying out this crucial test.

The module was lifted down for some meters inside the shaft.







IN THE MEANTIME…….

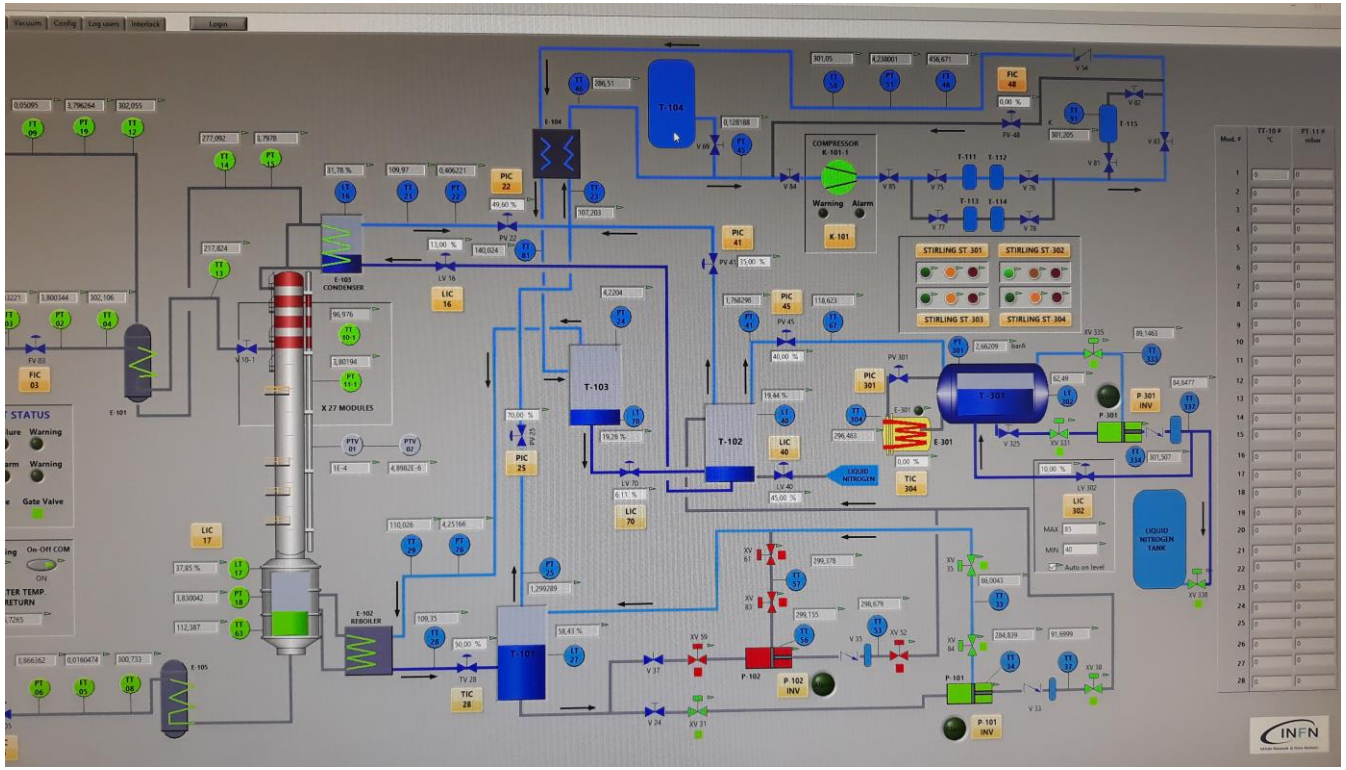
SERUCI 0

The prototype ARIA column is working

SERUCI 0

Fully installed in a Carbosulcis building.

It is made of the column itself and all the auxiliary equipment.

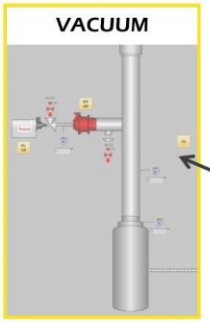


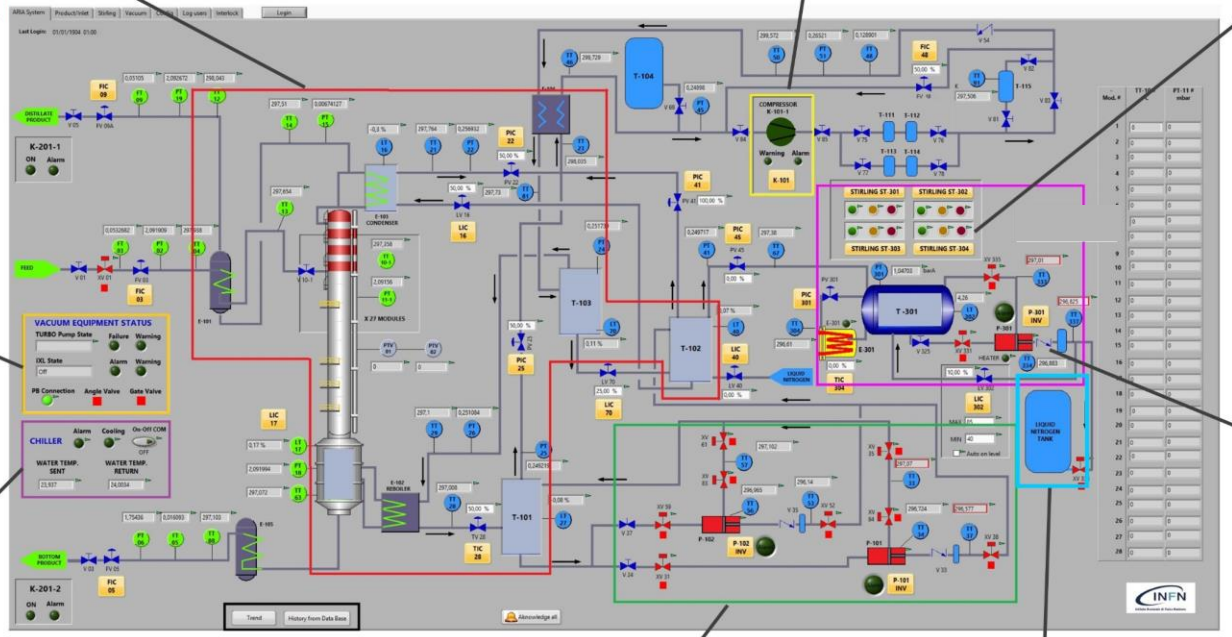
The column is a shorter version than ARIA.
It is made of only 1 central module + top and bottom modules.
It is 26m high.
It is held by an ad-hoc reticular beam structure.

AUXILIARY EQUIPMENT

COLD BOX

VACUUM





CHILLER

VANZETTI

SOL TANK (LN)

TEST

2019 – $^{29}N_2$ / $^{28}N_2$

- The separation between two isotopes of nitrogen has been observed.
- The Seruci-0 plant and auxiliary components and devices have been successfully tested.
- For more details see: Eur. Phys. J. C (2021) 81:359

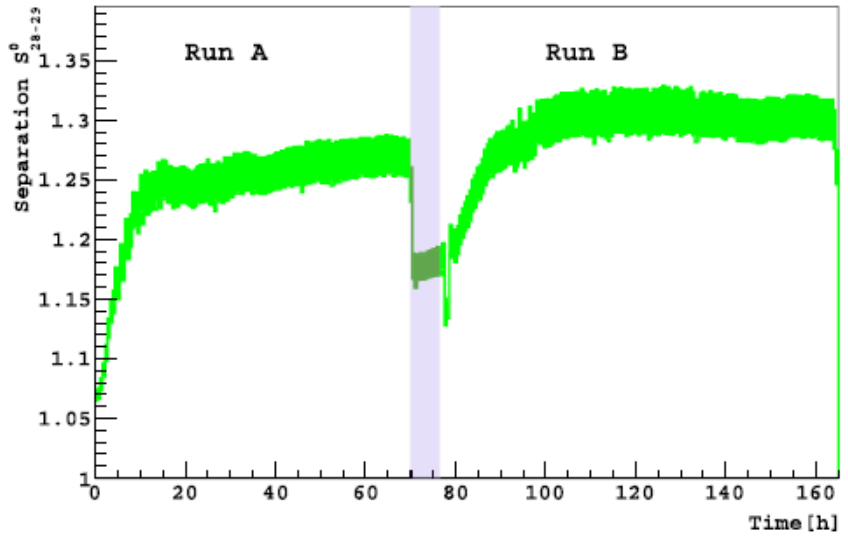


Fig. 17 Separation factor S^0_{28-29} for $^{29}N_2$–$^{28}N_2$ distillation in the prototype plant. The band represent the systematic uncertainty from the spectrometer calibration

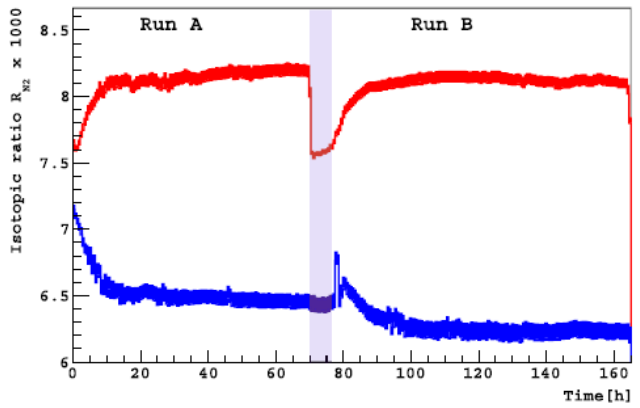


Fig. 16 Reboiler (red) and condenser (blue), isotopic ratio R_{N_2} vs. time for $^{29}N_2$–$^{28}N_2$ distillation in the prototype plant, after spectrometer calibration. The bands represents the systematic uncertainty from the spectrometer calibration

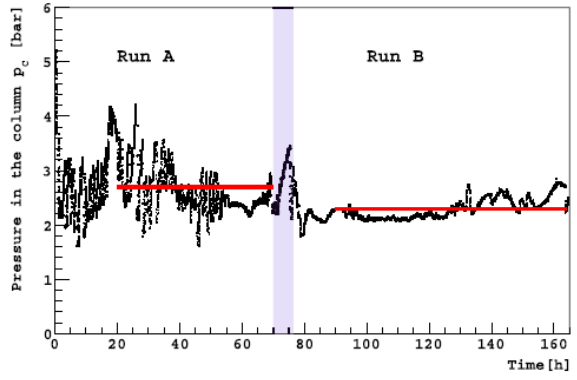


Fig. 14 Measured pressure inside the column, p_C, in the top vs time, for $^{29}N_2$–$^{28}N_2$ distillation in the prototype plant. The red horizontal lines indicate the average pressure values in Run A and Run B of 2.7 bar and 2.3 bar, respectively. The averages are taken only for time periods after the distillation transients of both runs are over, as observed in Fig. 16

TEST

2021 – $^{36}Ar/\ ^{40}Ar$ & $^{38}Ar/\ ^{40}Ar$

- The separation between three isotopes of argon has been observed.
- The pressure inside the column. Has been stabilised.
- A good automatism of the plant has been reached.
- The simulations have been confirmed and validated.
- We become more confident with the plant.
- For more details see: Eur. Phys. J. C 83 (2023) 5, 453

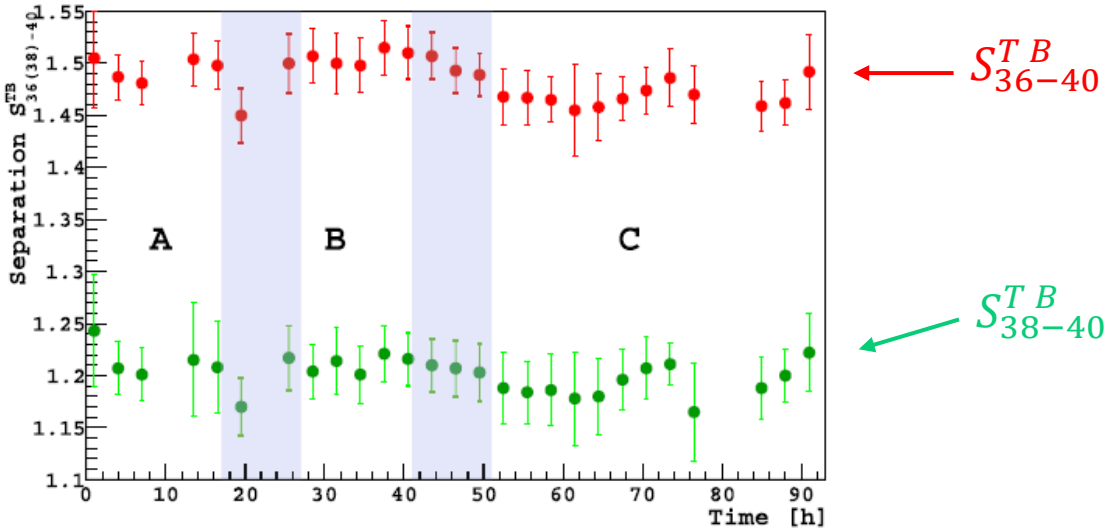


Fig. 7 Separation S^{TB}_{36-40} (red) and S^{TB}_{38-40} (green) as a function of time. The shaded regions correspond to changing conditions in the column (see Fig. 2) and are not included in the data analysis

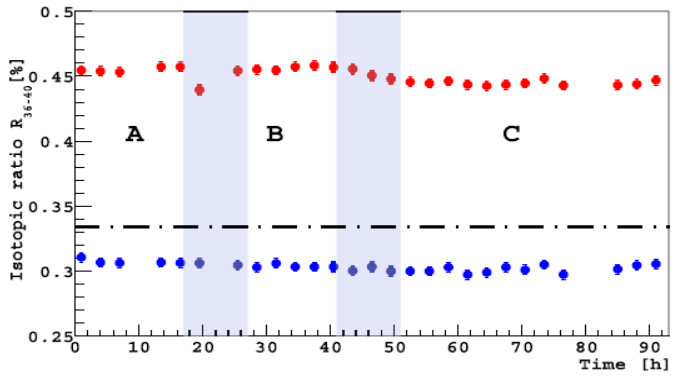
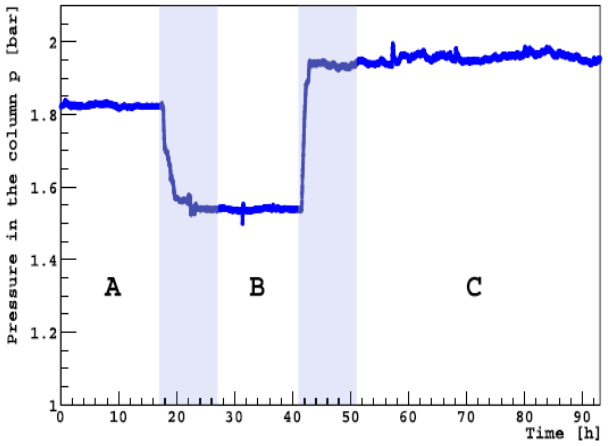
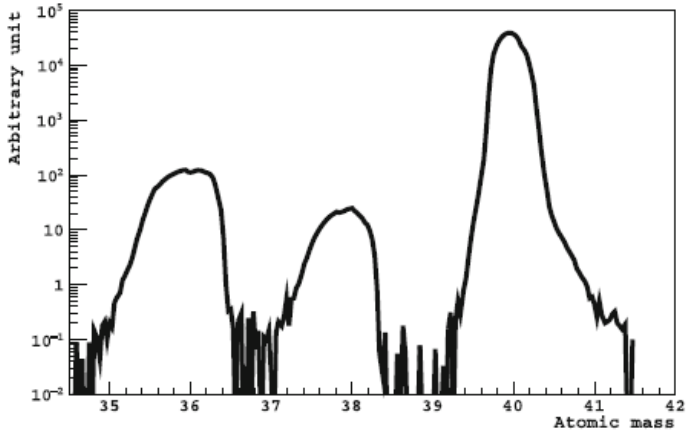
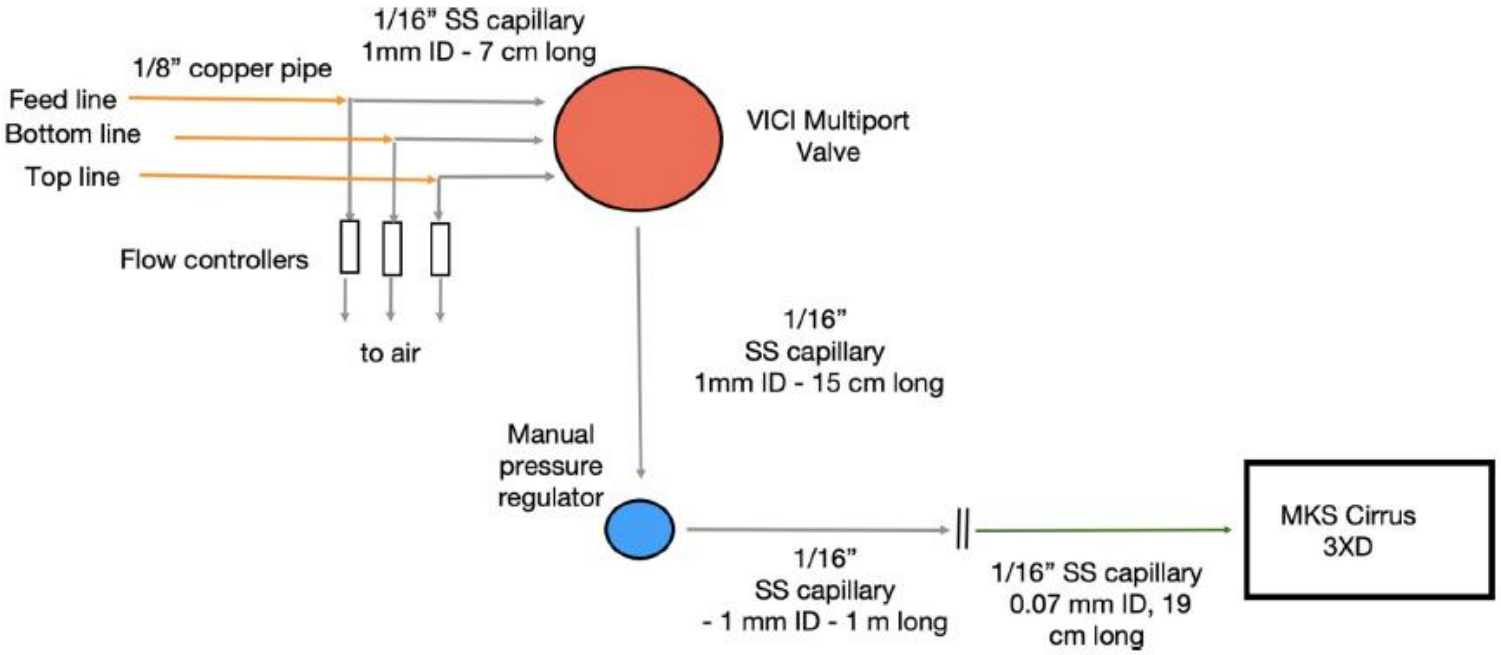


Fig. 6 The isotopic ratios $(R_{36-40})_T$ (red) and $(R_{36-40})_B$ (blue) as a function of time, after correction using the measured isotopic ratio in the feed, $(R_{36-40})_F$ (see text). The dashed-dotted line corresponds to the natural isotopic ratio. The shaded regions correspond to changing conditions in the column (see Fig. 2) and are not included in the data analysis




Credits: Riccardo Stefanizzi





SAMPLING SYSTEM

- Continuous sampling system
- MKS Instruments, Cirrus™ 3-XD quadrupole mass spectrometer

RADIOACTIVITY MEASUREMENTS

DArT

See the talk: "Monitoring ^{39}Ar Background for DarkSide-20k with DArTinArDM" by Daniel Díaz Mairena

TRANSPORTATION & STORAGE

- Currently the collaboration is evaluating different containers (also liquid) and have not yet made a final decision.
- Cosmogenic activation can be kept under control by minimizing exposure on the surface and storing materials underground, avoiding flights, and even using appropriate shields.
- For more detail about ^{39}Ar activation see the talk "Study of cosmogenic activation above ground of Ar for DarkSide-20k" by Susana Cebrian.

Example of std cryogenic container
https://wessingtoncryogenics.com/

OTHER EXPERIMENTS YEARNING UAr

We recently signed with the LEGEND Collaboration an agreement for the provision of 25 t of UAr for the LEGEND1000 argon veto, after the DarkSide-20k production

—> suppression of ^{42}Ar

- A lot of interest in the UAR from other experiments
  - COHERENT 1 t (CEvNS)
  - **ARGO 400t (dark matter)**
  - DUNE MoO O(10,000) t (Dark matter, SNv, 2β0ν); MoO Workshop 2022 (https://congresos.adeituv.es/dune_science/)

Credits: WB, TAUP 2023 Vienna

THANK YOU