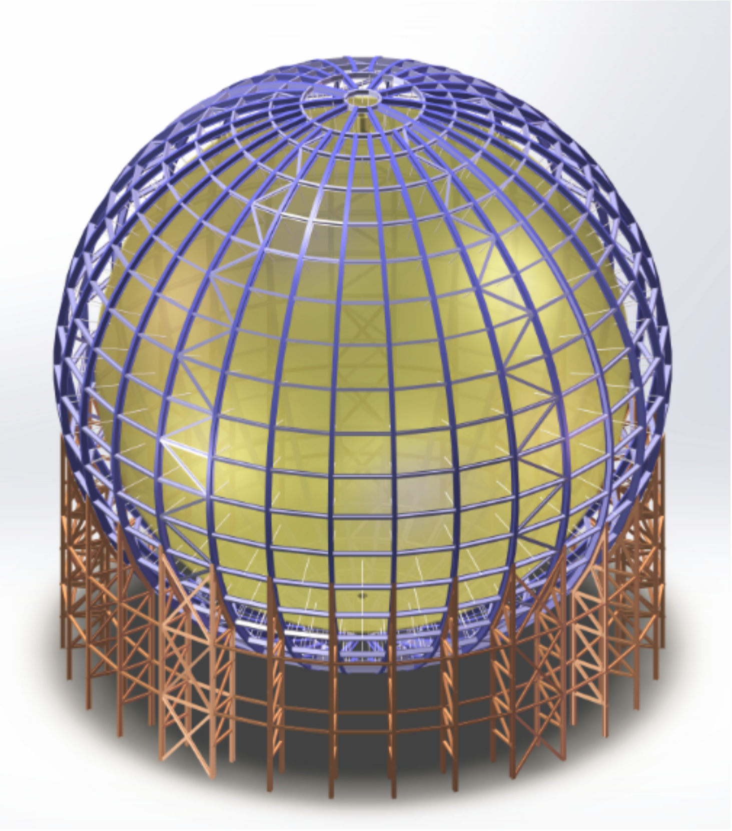


Updates on background measurements and JUNO background control

Monica Sisti

INFN Milano-Bicocca

JUNO-Italia Meeting, Milano 5-6 maggio 2022

Content

- Acrylic mass production control and surface cleaning
- Noble gases inside acrylic panels
- Liquid scintillator laboratory radiopurity measurement

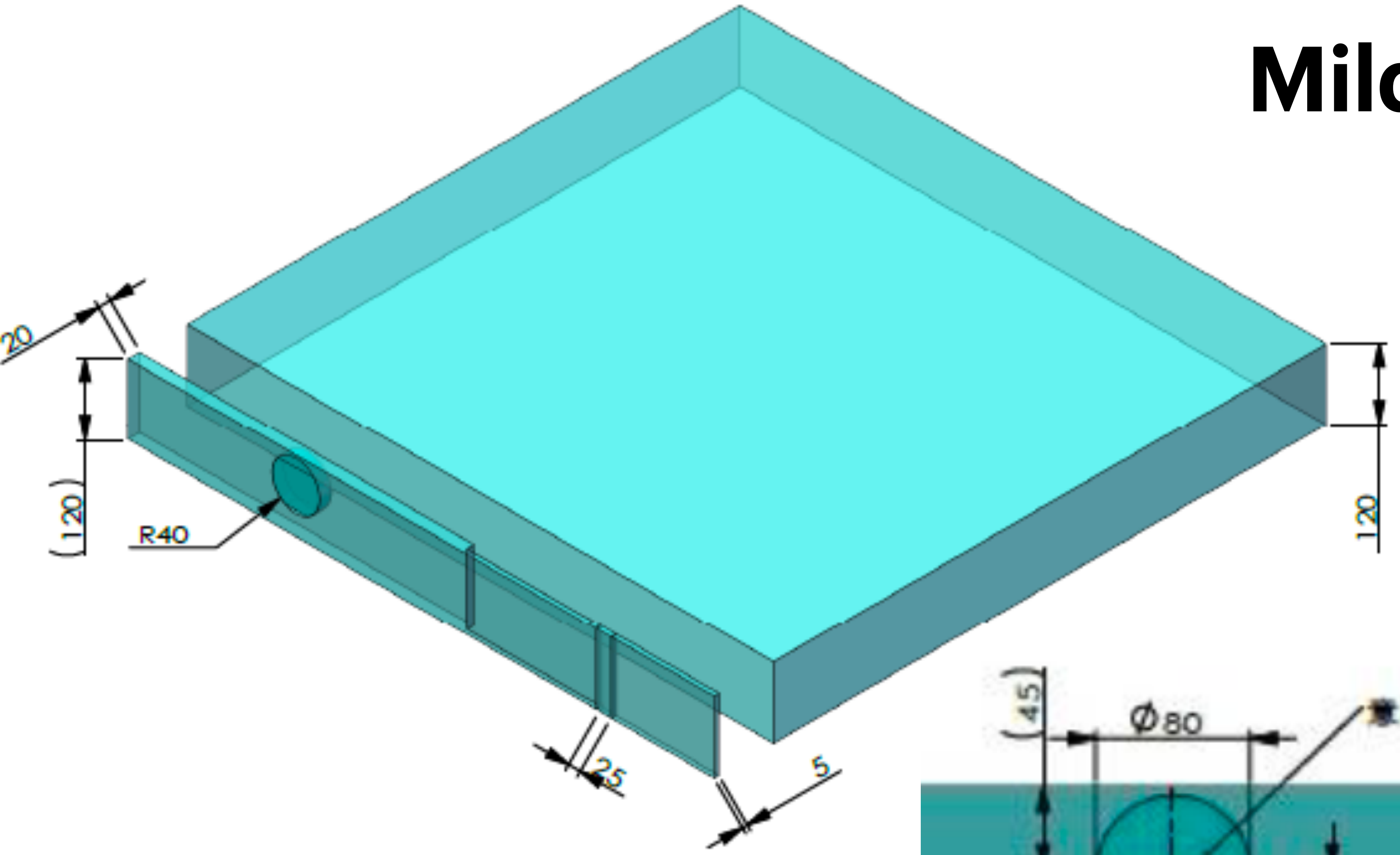
  → *(see Massimiliano's talk)*

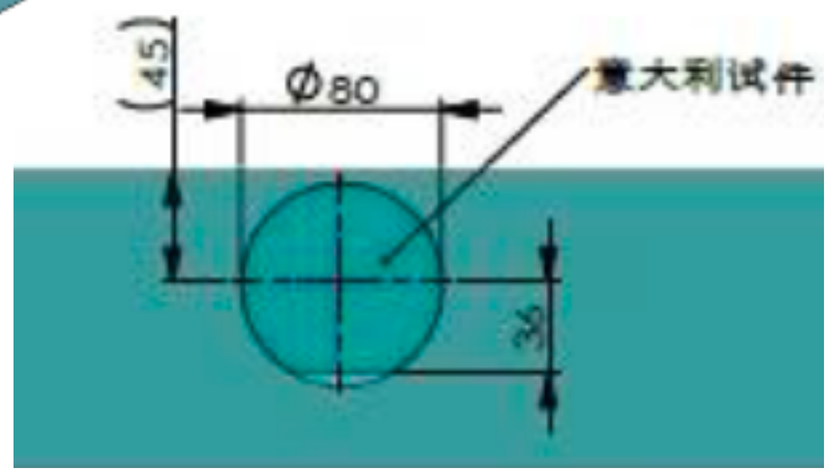
- JUNO Detector filling scheme

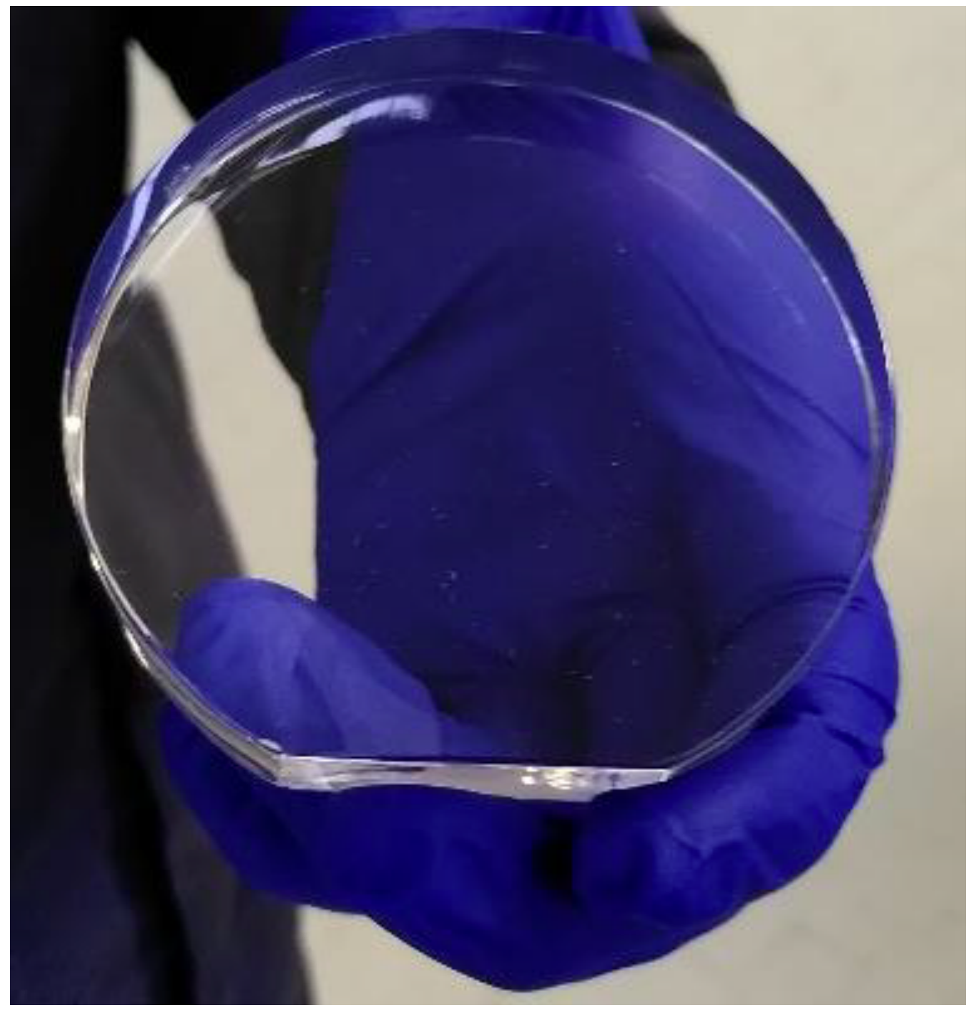
Acrylic mass production control

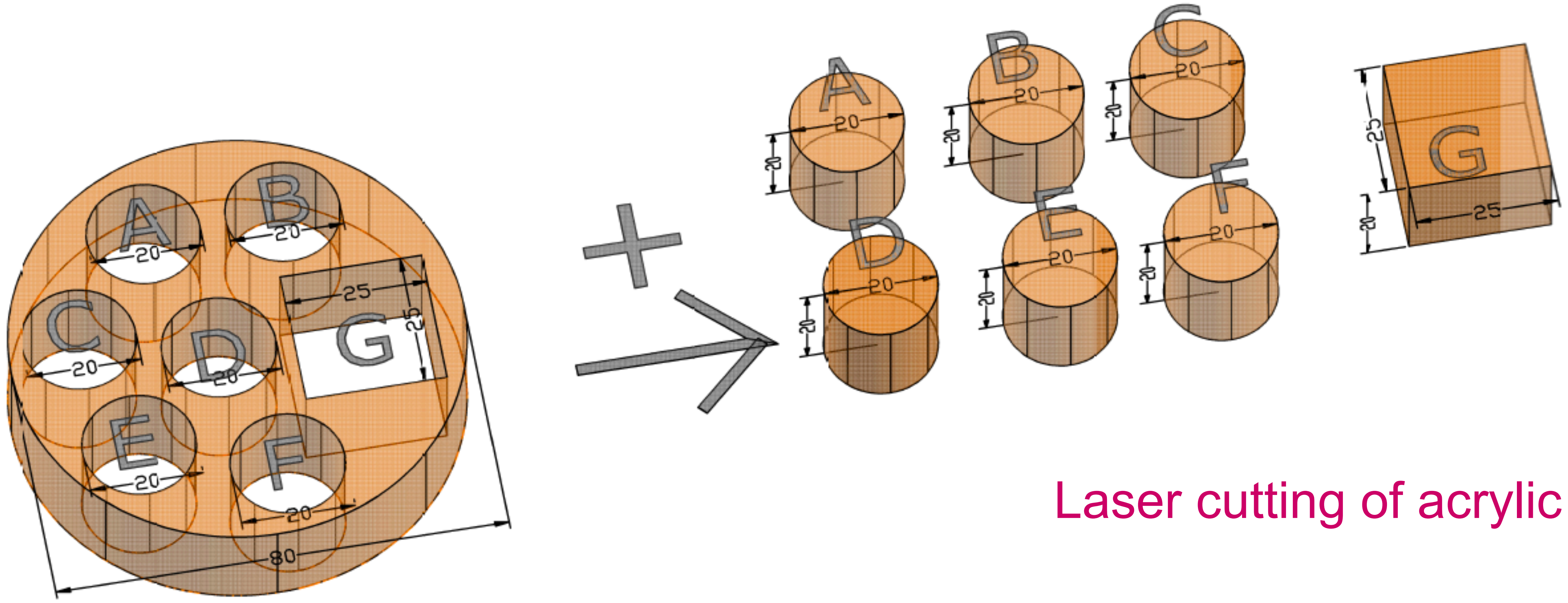
Acrylic screening by NAA

Milano-Bicocca Radioactivity Lab









Laser cutting of acrylic samples

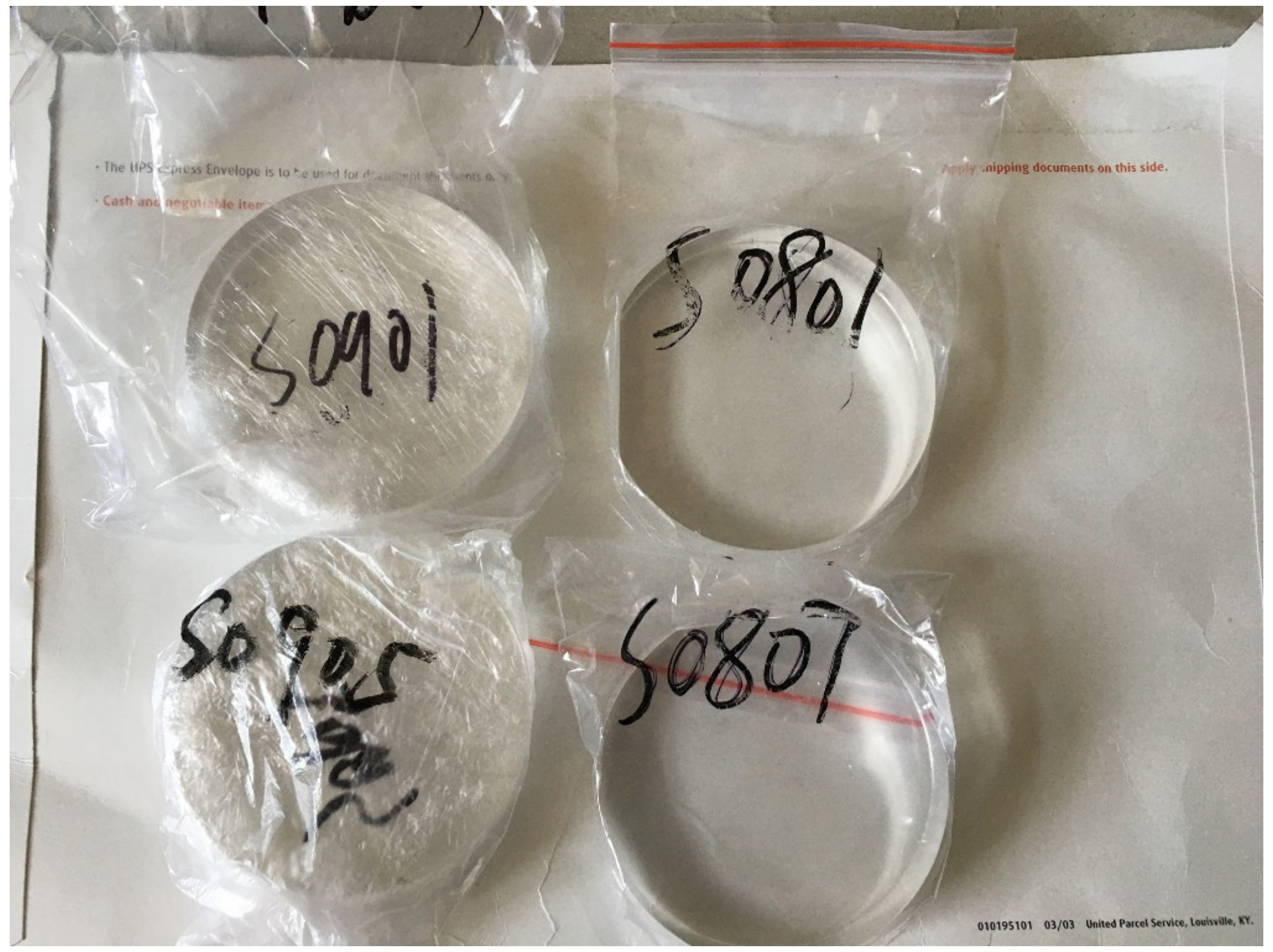
Small cylinders: mass ~7g

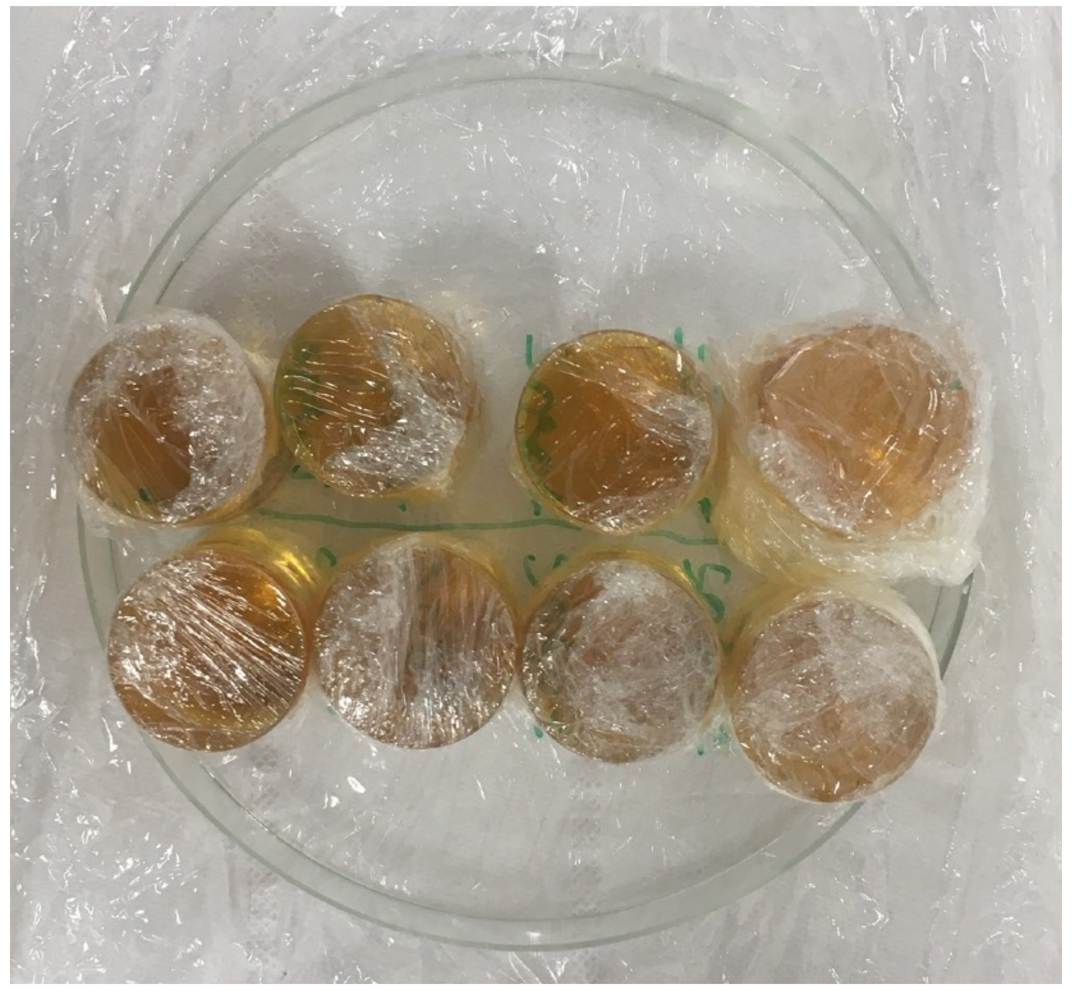
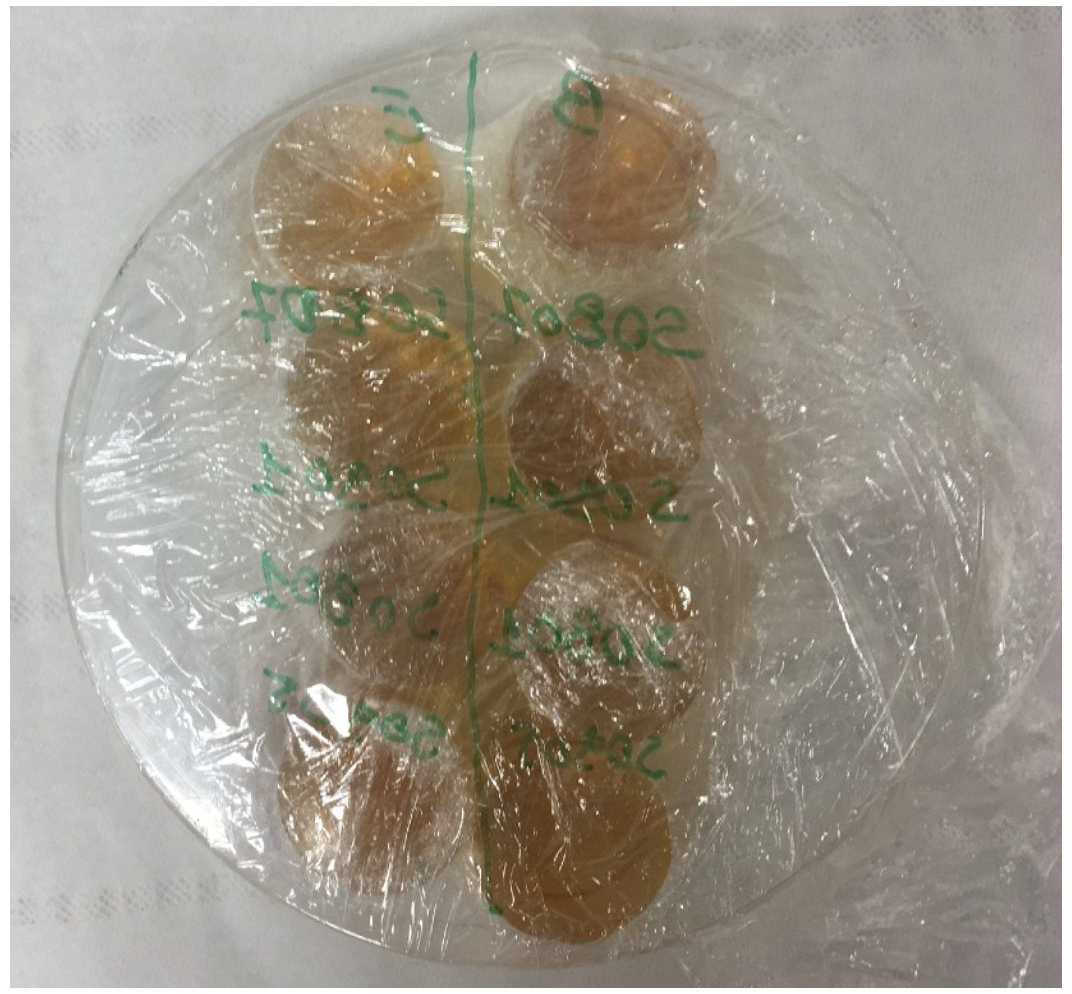
Acrylic screening by NAA

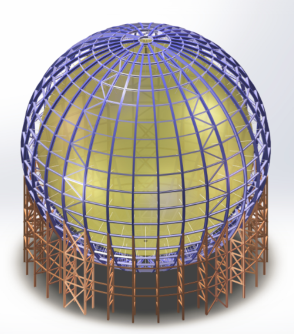
Delivery #4

Delivery of July 2021

- Samples from panels: S0801, S0807, S0901, S0905.
- Irradiated and measured together in the irradiation campaign of September 28, 2021.
- 2 cylinders per panel, from positions B and E
- Total measuring time ~30 days





Acrylic screening by NAA

Delivery #4

Delivery of July 2021

- ^{40}K contamination was present on all samples (most likely on the surface)

Sample	Mass [g]	^{40}K [ppt]	^{238}U [ppt]	^{232}Th [ppt]
4 cylinders: S0801E, S0807E, S0901B, S0905B,	28.2	13.1 ± 0.2	—	—
8 cylinders: S0801(B/E), S0807(B/E), S0901(B/E), S0905(B/E)	56.4	10.6 ± 0.2	< 0.36	< 0.39

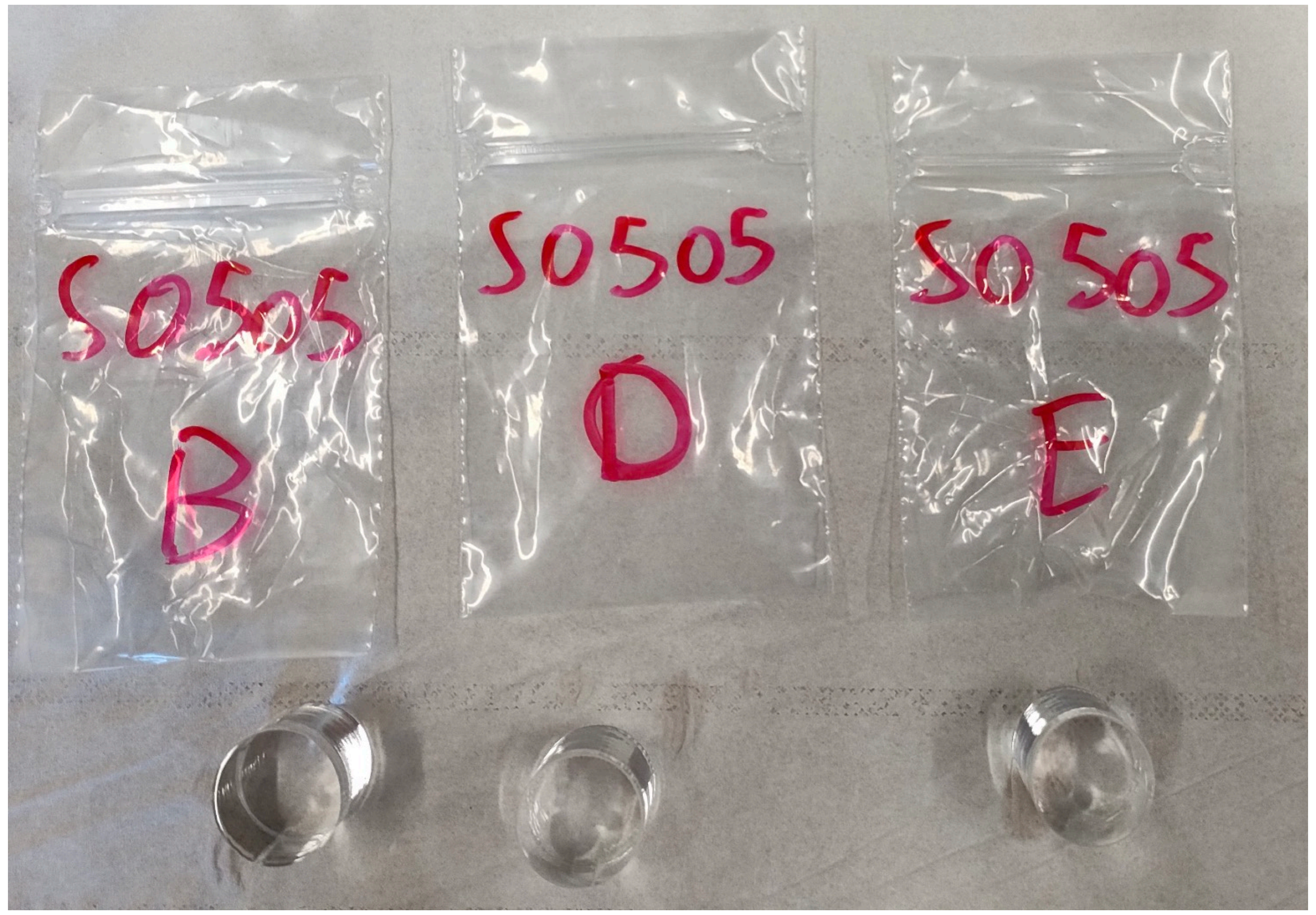
It is mandatory to understand what went wrong with the cleaning of these samples

Acrylic screening by NAA

Delivery #5

Delivery of December 2021

- Samples from panels: S0701, S0707, S0601, S0607, S0613, S0501, S0505, S0509, S0513.
- Irradiation campaign postponed to February 14, 2022 (several issues at the reactor).
- Measured two panels, **S0505** and **S0701**, 3 cylinders each.



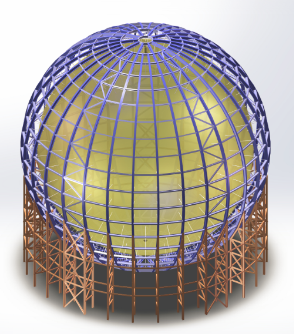
Acrylic screening by NAA

Delivery #5

Delivery of December 2021

- ^{40}K contamination is present on all surfaces (not uniformly distributed); it is located in the first 0.5—1 mm (calculated by mass removal on the flat surfaces of the cylinders).
- **Surface cleaning protocols must be revised.**

Sample	Mass [g]	^{40}K [ppt]	Mass [g]	^{40}K [ppt]	Mass [g]	^{40}K [ppt]
3 cylinders: S0701-A, S0701-D, S0701-F	21.37	11.03 ± 0.13	—	—	—	—
1 cylinder: S0701-A	7.11	7.98 ± 0.25	6.70*	1.17 ± 0.19	6.39*	0.60 ± 0.04
3 cylinders: S0505-E, S0505-B, S0505-D	21.30	3.69 ± 0.10	—	—	—	—
1 cylinder: S0505-E	7.12	2.27 ± 0.08	6.75*	< 0.05	—	—



Acrylic screening by NAA

Delivery #5

Delivery of December 2021

- ^{238}U and ^{232}U are compliant with JUNO requirements

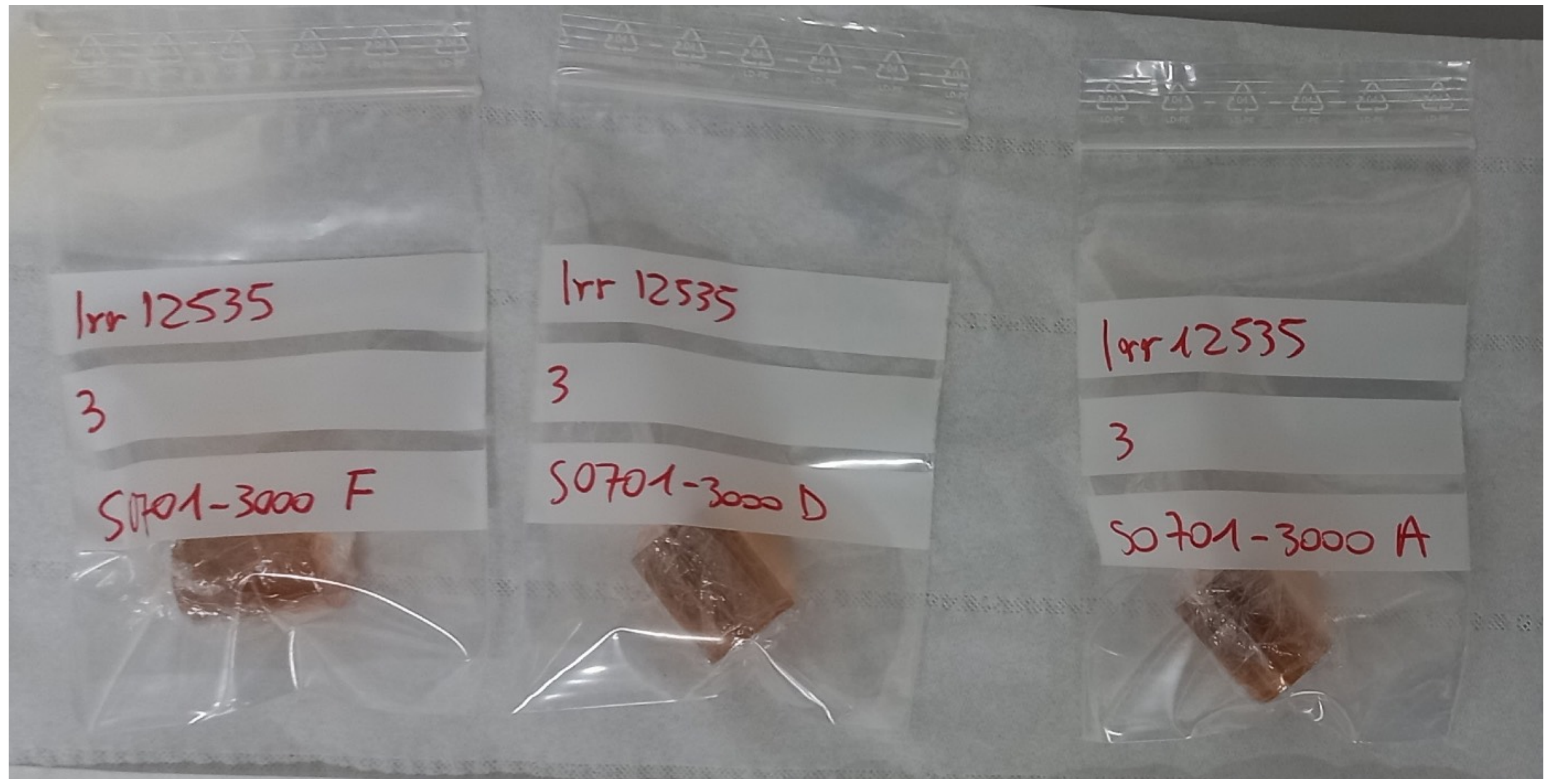
Sample	Mass [g]	^{40}K [ppt]	^{238}U [ppt]	^{232}Th [ppt]
4 cylinders: S0505-B, S0505-D, S0701-D, S0701-F	28.44	see previous slide	< 0.24	< 0.38
2 cylinders: S0505-E, S0701-A *(after surface removal)*	13.14	see previous slide	< 0.49	< 0.97

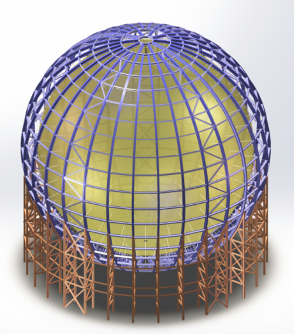
Acrylic screening by NAA

Delivery #6

Delivery of April 2022

- Samples from panels S0701 and S0505 (same of previous delivery) with modified surface cleaning: **only sanding + washing** with DI water (no detergent); **no polishing**. Two different sanding meshes were used: 2000 and 3000.
- Irradiation campaign on April 27, 2022.
- Measured panels **S0701-2000** and **S0701-3000**, 3 cylinders each.





Acrylic screening by NAA

Delivery #6

Delivery of April 2022

- ^{40}K contamination is within JUNO requirements.
- **Acrylic transparency must be checked.**
- ^{238}U and ^{232}Th measurement is ongoing.

Sample	Mass [g]	^{40}K [ppt]	Mass [g]	^{40}K [ppt]
1 cylinder: S0701-2000-A	8.91	0.19 ± 0.02	8.84*	< 0.02
3 cylinders: S0701-3000-A, -D, -F	26.76	< 0.08	—	—

*removed ~ 95 μm

Noble gases in acrylic

Noble gases inside acrylic samples

- ^{39}Ar (cosmogenic) and ^{85}Kr (nuclear tests) are a dangerous background source for our experiment, in particular for the solar neutrino channel: they are present in the atmosphere.

$$^{39}\mathbf{Ar}\ \left(T_{\frac{1}{2}} = 269\ yr\right)$$

$$^{85}\mathbf{Kr}\ \left(T_{\frac{1}{2}} = 10.756\ yr\right)$$

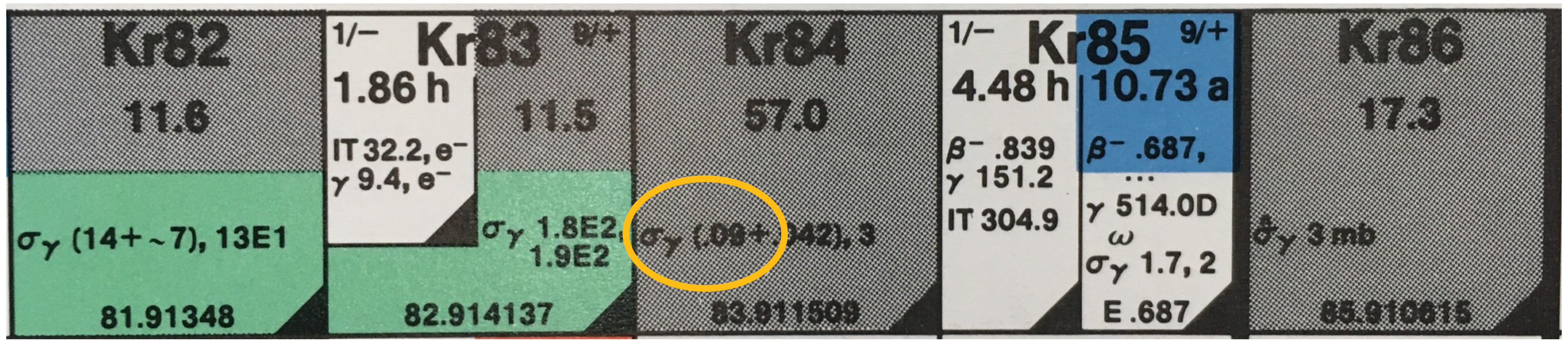
- Argon and Kripton stable nuclides are present in the air. After neutron irradiation, their activation products can be measured by gamma spectroscopy:

$$^{40}_{18}Ar \rightarrow\ ^{41}_{18}Ar\ \left(T_{\frac{1}{2}} = 109.34\ m\right)$$

E_γ = 1293.6 keV

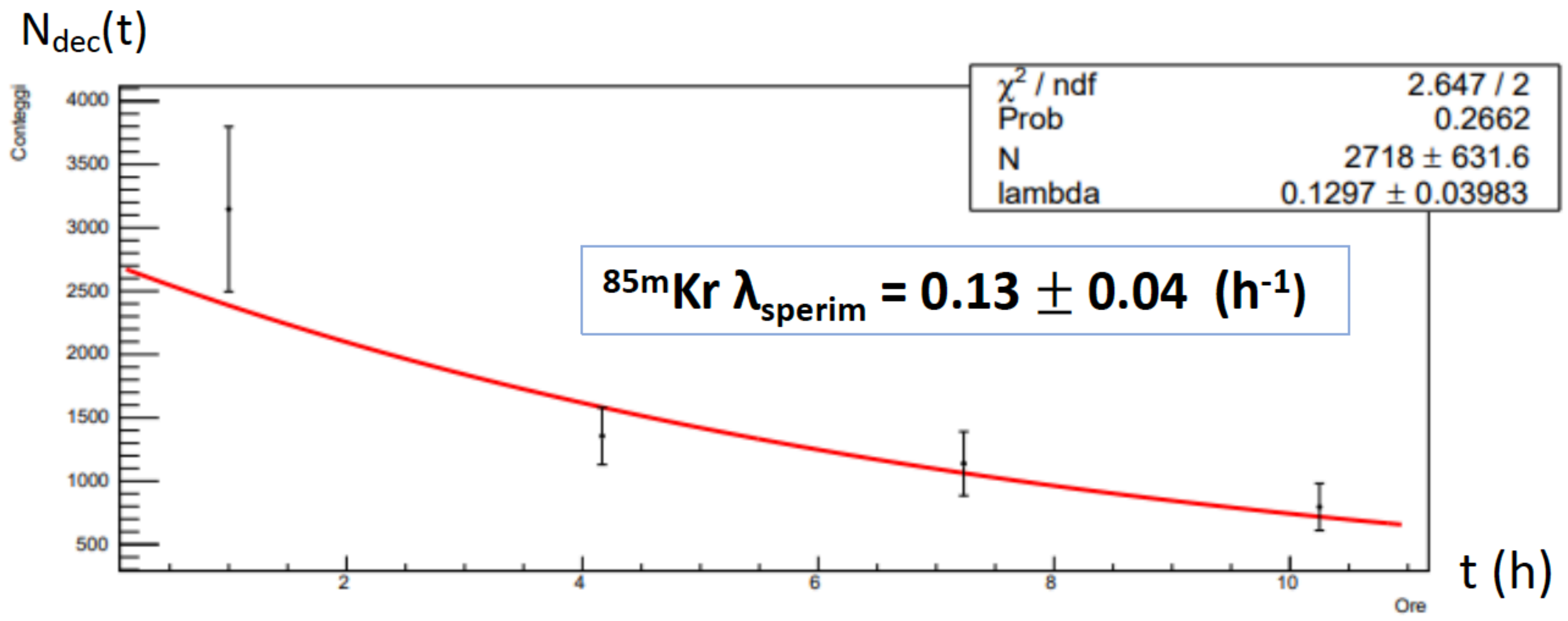
$$^{84}_{36}Kr \rightarrow\ ^{85m}_{36}Kr\ \left(T_{\frac{1}{2}} = 4.48\ h\right)$$

E_γ = 151.2 keV



Noble gases inside acrylic samples

- We measured the decay constant of the line at 151 keV and demonstrated that it is indeed Kripton!



$$^{84}_{36}Kr \rightarrow\ ^{85m}_{36}Kr\ \left(T_{\frac{1}{2}} = 4.48\ h\right)$$

E_γ = 151.2 keV

$\lambda_{att} = 0.15472\ (h^{-1})$

- We detected also Xenon activated isotopes:

$$^{132}_{54}Xe \rightarrow\ ^{133}_{54}Xe\ \left(T_{\frac{1}{2}} = 5.243\ d\right)$$

$$^{124}_{54}Xe \rightarrow\ ^{125}_{54}Xe\ \left(T_{\frac{1}{2}} = 16.9\ h\right)$$

Noble gases inside acrylic samples

Delivery of December 2021

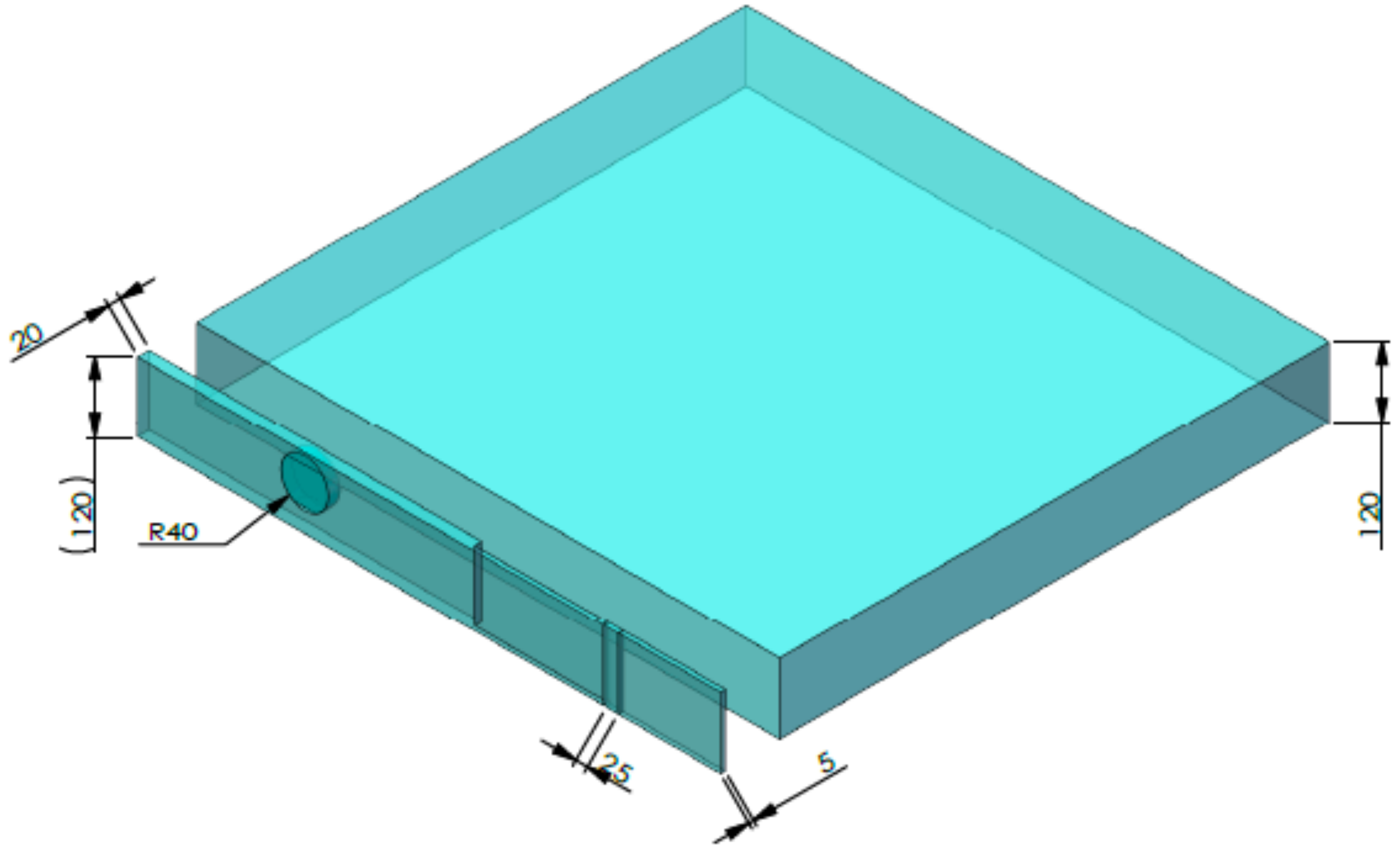
- Noble gases can be measured by NAA. We were able to detect the presence of Ar, Kr, Xe in our samples, following their concentration in the atmosphere and subsequent diffusion (?) inside the acrylic.

Sample	Mass [g]	Argon [10^{-6} g/g]	Kripton [10^{-9} g/g]	Xenon [10^{-10} g/g]
3 cylinders: S0701-A, S0701-D, S0701-F	21.37	2.27 ± 0.09	1.69 ± 0.36	5.25 ± 0.67*
3 cylinders: S0505-E, S0505-B, S0505-D	21.30	2.06 ± 0.08	1.56 ± 0.22	5.72 ± 0.73*

** values calculated on a different set of samples*

Noble gases inside acrylic samples

What can we say about the measured noble gas concentrations?



Atmospheric concentration of noble gases:

- Argon –> 9340 ppmv (M=39.95)
- Kripton –> 1.099 ppmv (M=83.80)
- Xenon –> 0.087 ppmv (M=131.30)

For Xenon we did not find suitable data (Solubility and Diffusion constant) in the literature yet (we are working on it…)

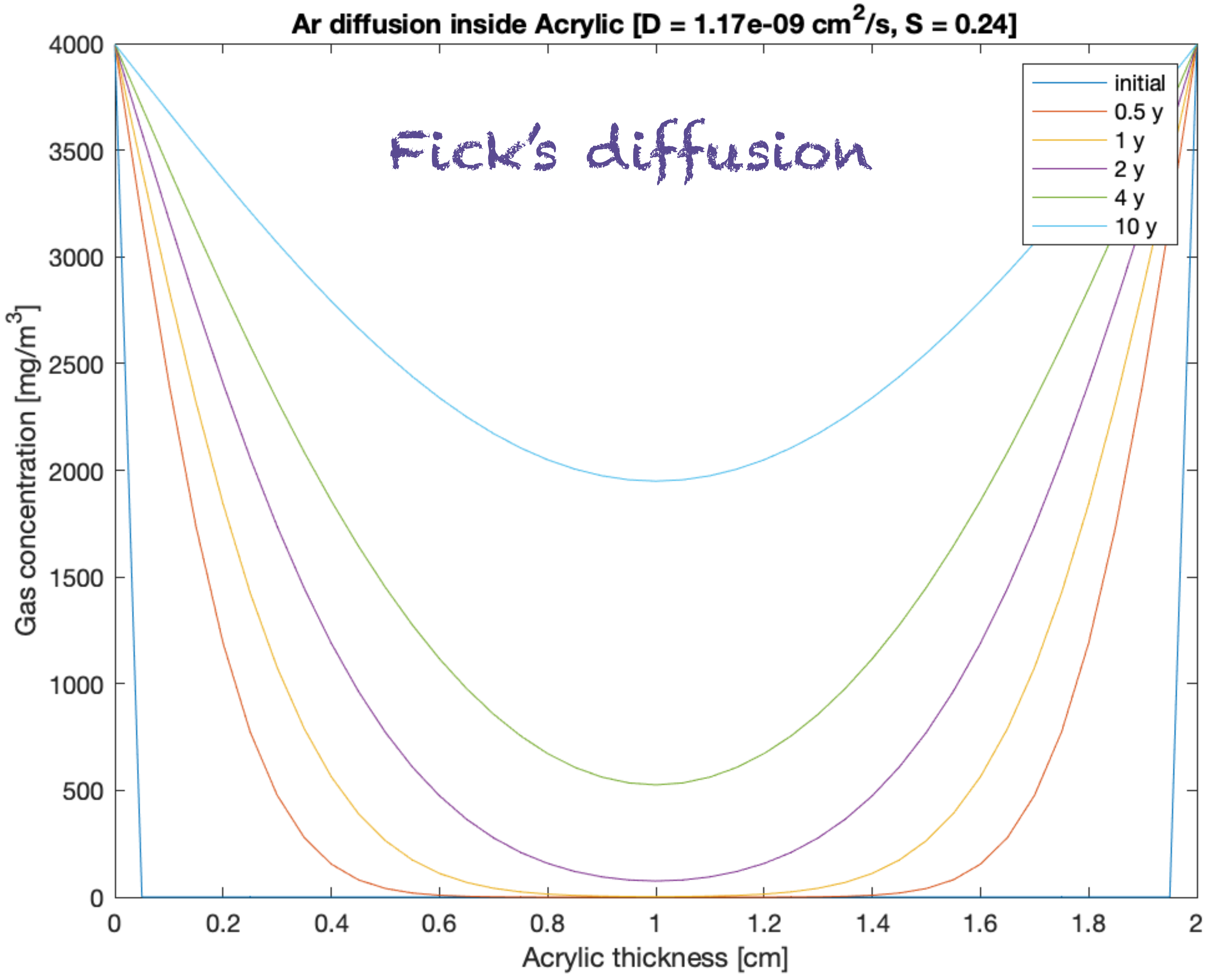
Assuming the atmospheric concentration of Xenon inside the acrylic cylinder (i.e. acrylic saturated with Xenon at production), we expect:

$C_{Xe} = 4.6\times10^{-10}$ g/g

(measured: ~ 5.5×10^{-10} g/g)

Noble gases inside acrylic samples

What can we say about the measured noble gas concentrations?



Assuming Fick's diffusion inside the acrylic cylinder, the expected Argon concentration is:

- 1 year exposure –> 1.5×10^{-6} g/g
- 2 year exposure –> 2.1×10^{-6} g/g
- 4 year exposure –> 2.9×10^{-6} g/g
- 10 year exposure –> 4.6×10^{-6} g/g

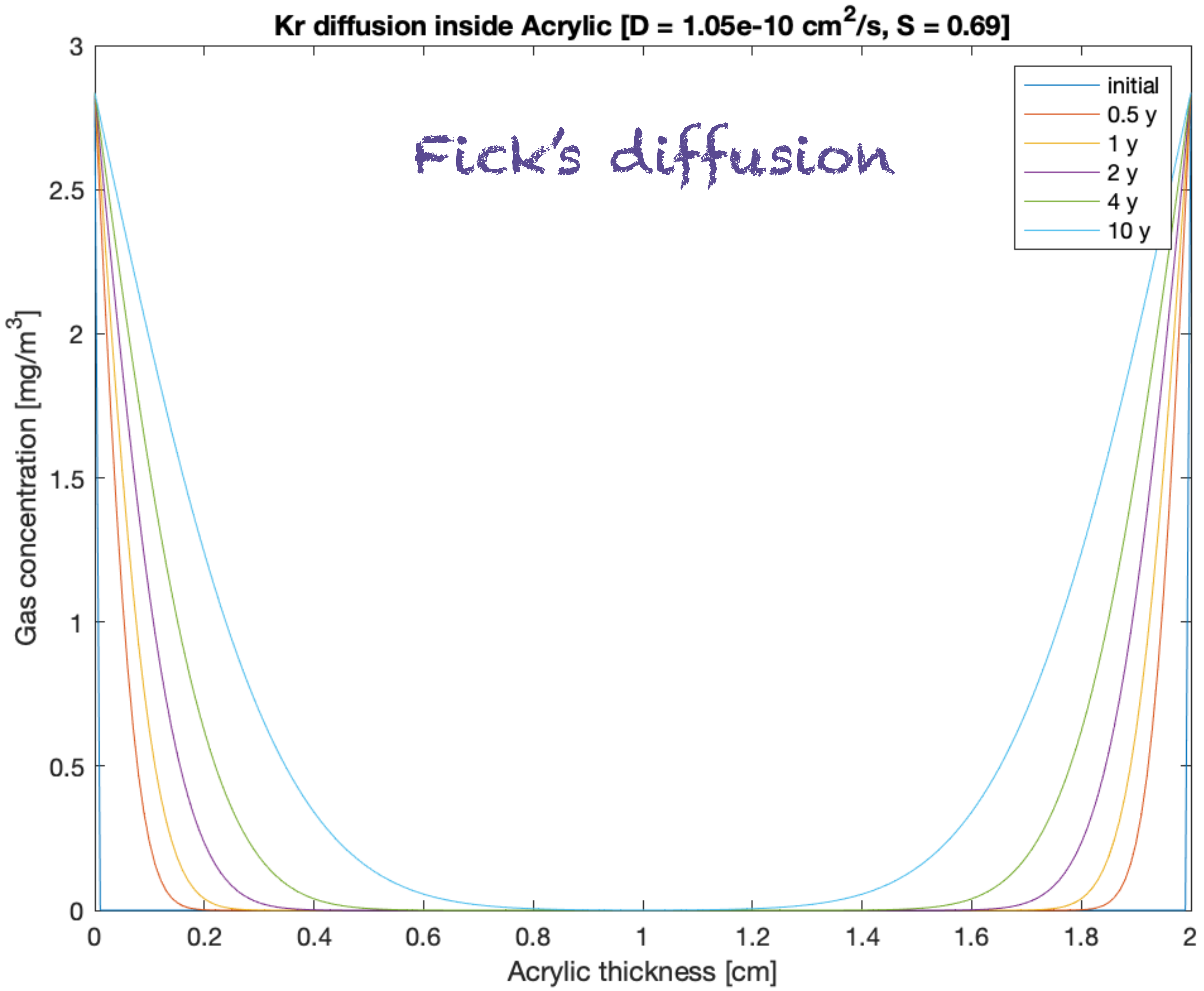
(measured: ~ 2.2×10^{-6} g/g)

Assuming the atmospheric concentration of Argon inside the acrylic cylinder (i.e. acrylic saturated with Argon at production), we expect:

$$C_{Ar} = 1.5\times10^{-5} \text{ g/g}$$

Noble gases inside acrylic samples

What can we say about the measured noble gas concentrations?



Assuming Fick's diffusion inside the acrylic cylinder, the expected Kripton concentration is:

- 1 year exposure –> 5.0×10^{-9} g/g
- 2 year exposure –> 7.1×10^{-9} g/g
- 4 year exposure –> 1.0×10^{-8} g/g
- 10 year exposure –> 1.6×10^{-8} g/g

(measured: ~ 1.6×10^{-9} g/g)

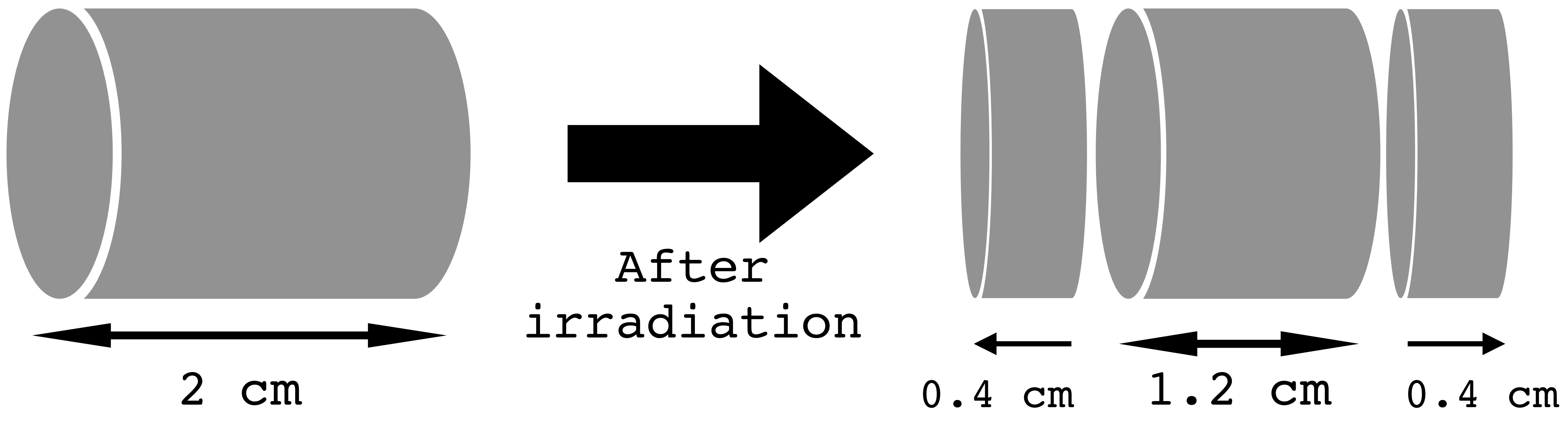
Assuming the atmospheric concentration of Kripton inside the acrylic cylinder (i.e. acrylic saturated with Kripton at production), we expect:

$$C_{Kr} = 3.7\times10^{-9} \text{ g/g}$$

Noble gases inside acrylic samples

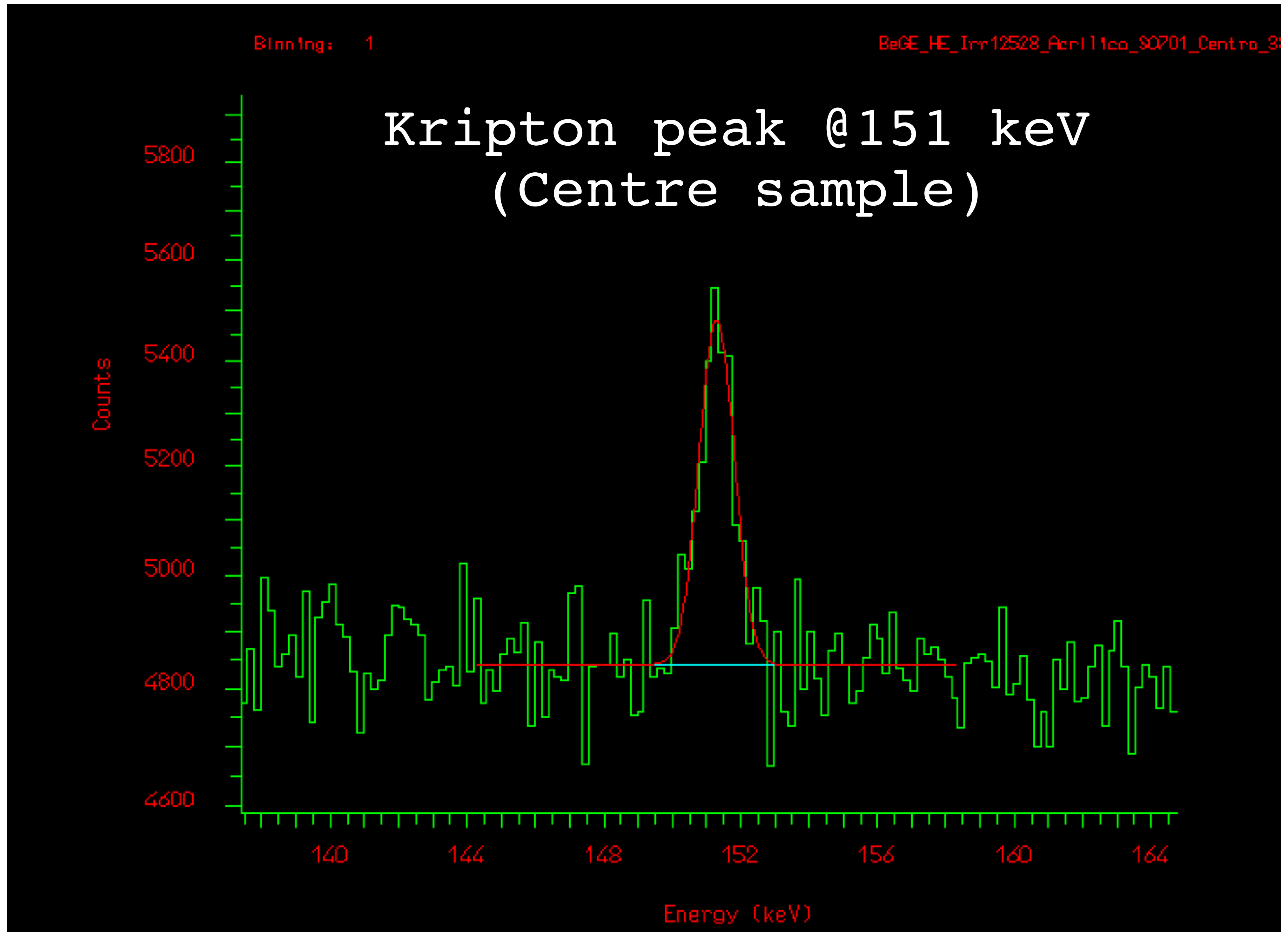
What can we say about the measured noble gas concentrations?

- Given the predicted diffusion inside the acrylic cylinder, we made another irradiation campaign and cut the sample afterwards:



- Measured the centre on one HPGe and the 2 ends on another HPGe.
- Preliminary results:

Centre: 1.1×10^4 counts/g
Ends: 1.0×10^4 counts/g
(error ~5%)

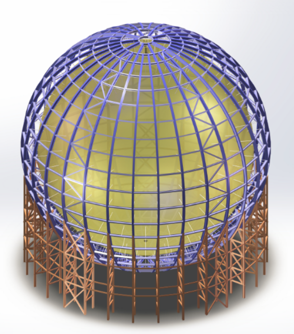


Noble gases inside acrylic samples

What 's next?

- Measurement of a freshly produced acrylic sample provided by Donchamp (not from JUNO batch) - should be arriving soon.
- Confirm previous measurements on additional samples.
- Evaluate impact on JUNO background in different scenarios.

JUNO detector filling scheme



JUNO Liquid Scintillator

Radiopurity requirements

	^{238}U	^{232}Th	^{226}Ra	^{40}K	^{210}Pb(^{222}Rn)	^{85}Kr/^{39}Ar
Requirement in LS	10^{-17} g/g 0.1 μBq/m^3	10^{-17} g/g 0.04 μBq/m^3	5×10^{-24} g/g 0.1 μBq/m^3	10^{-18} g/g 0.2 μBq/m^3	10^{-24} g/g 2.4 μBq/m^3 (5 mBq/m^3)	50 μBq/m^3
Contamination sources	Dust, water	Dust, water	Dust, water	Dust, water	Dust, Air/nitrogen, water	Air/nitrogen

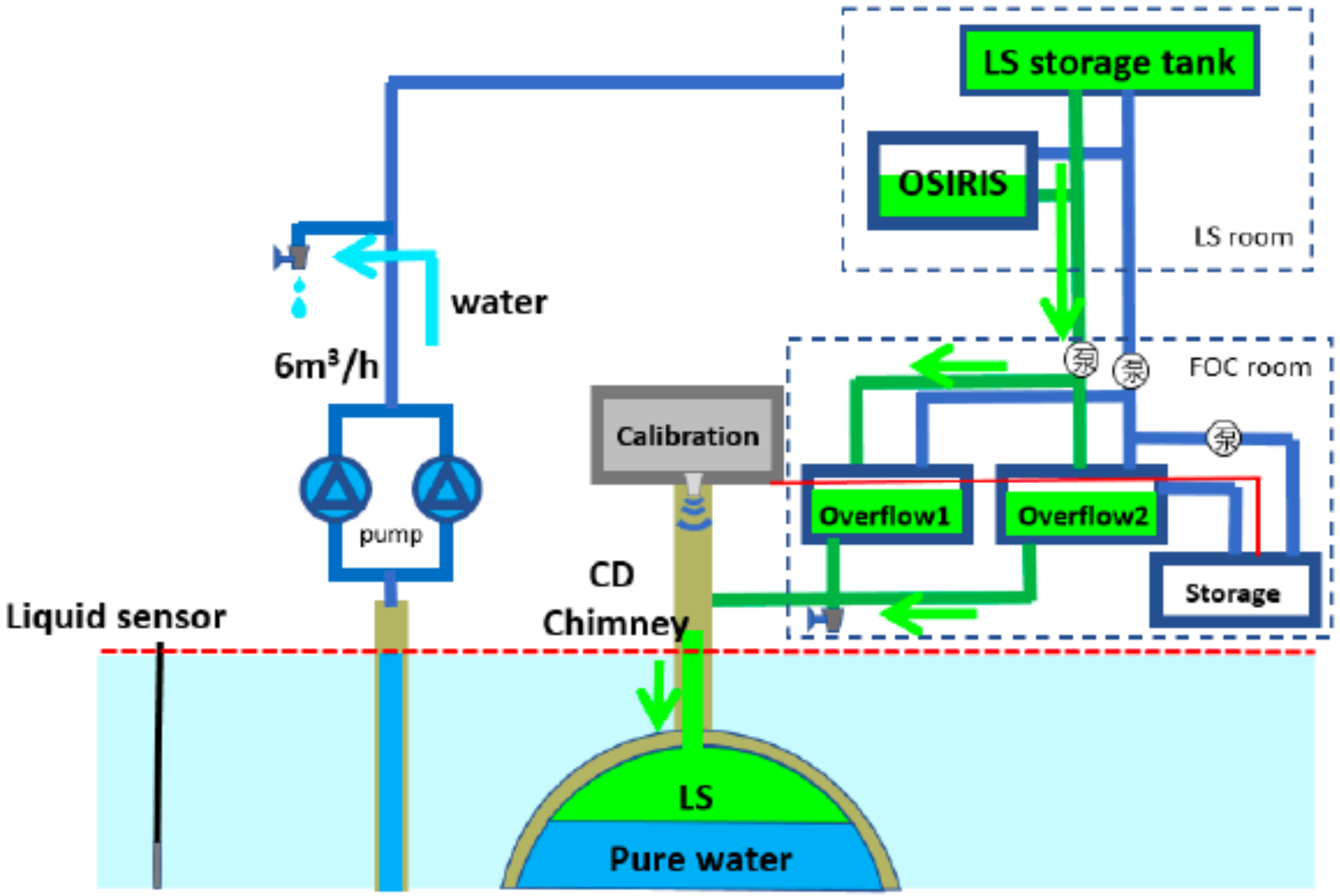
These requirements are crucial for our solar neutrino program and for future double beta decay searches.

No feasible way to reprocess the LS once it is inside the Acrylic Vessel: we should plan everything very carefully.

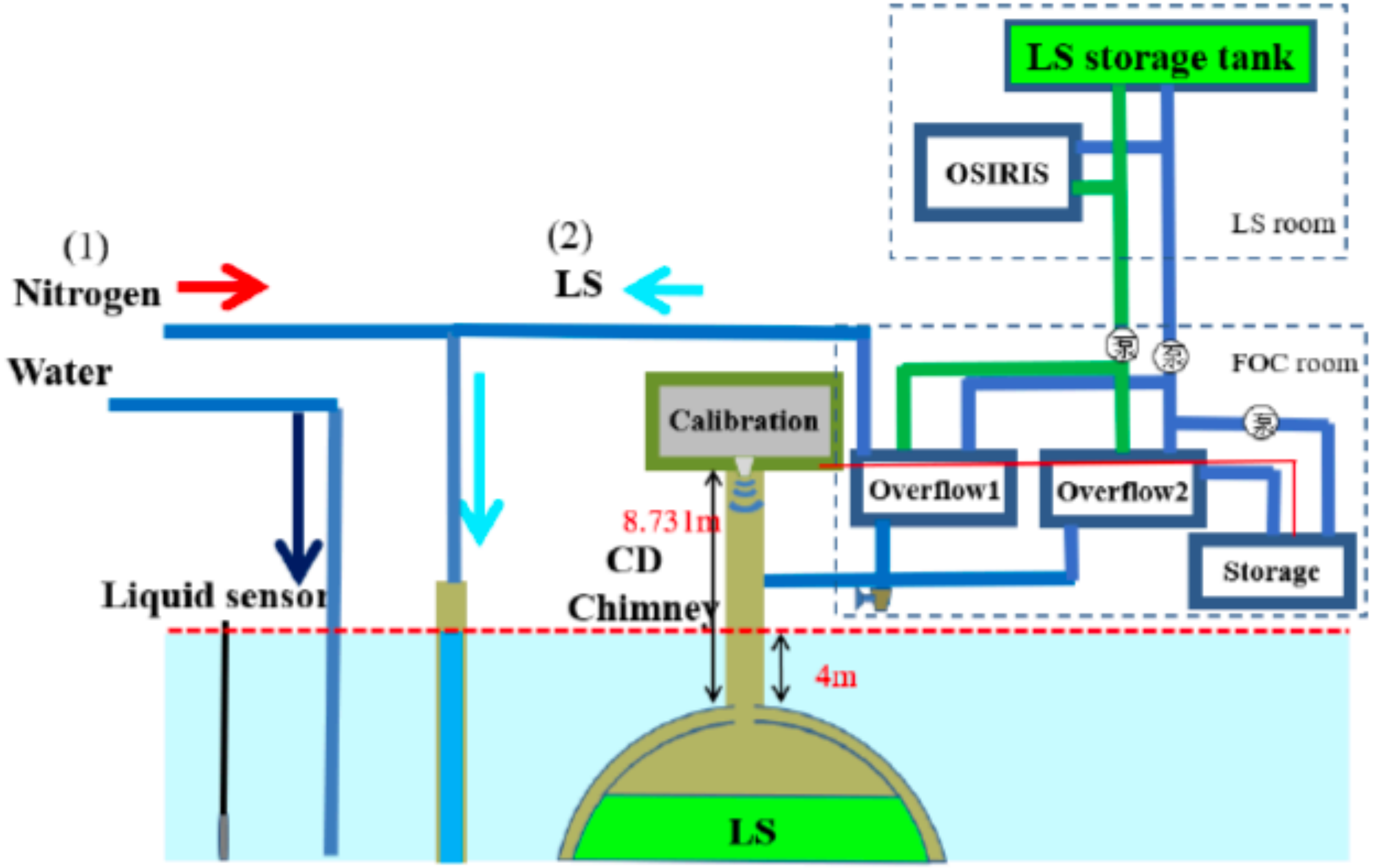
The detector filling

Two alternative choices

Water exchange



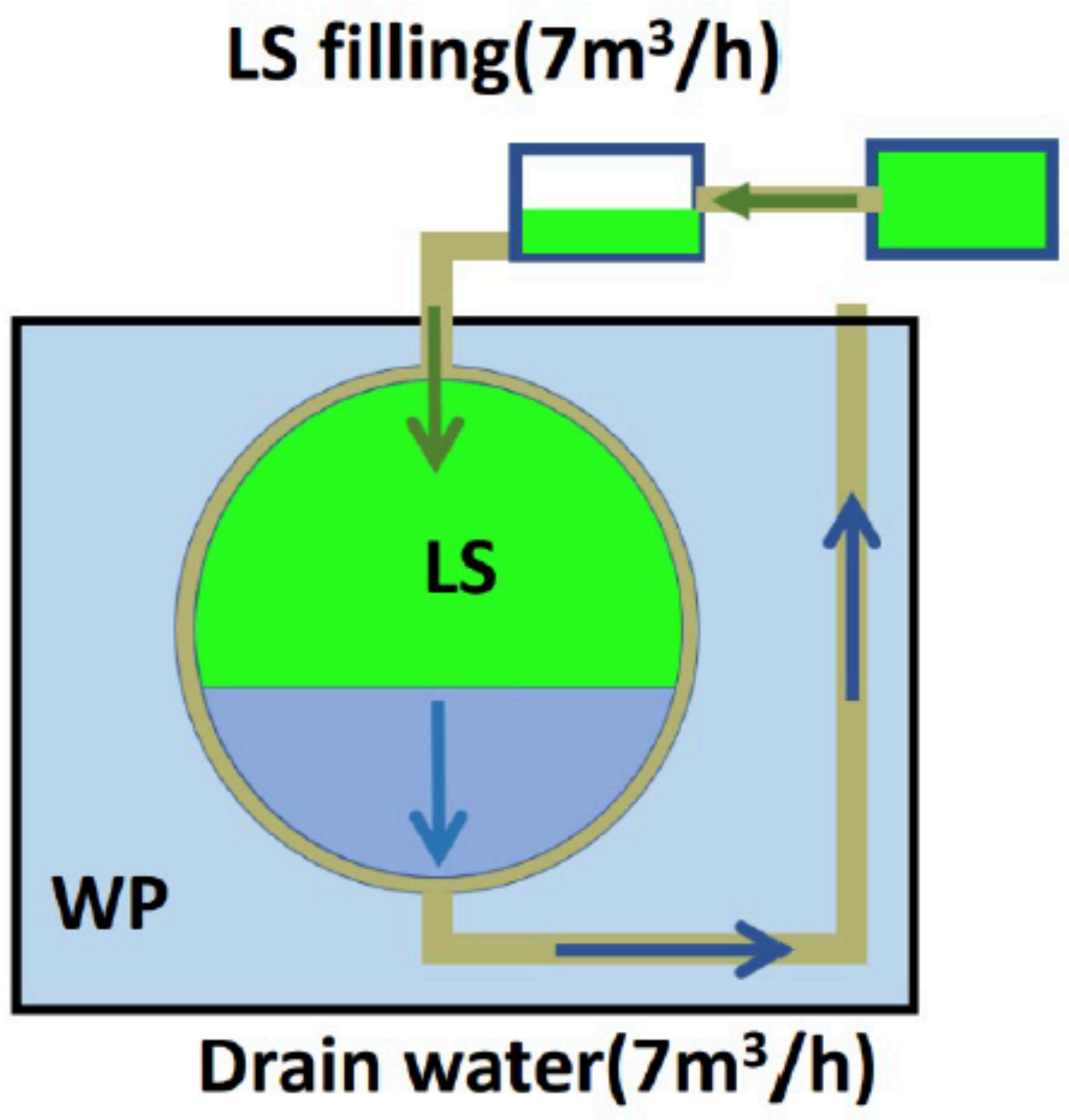
Nitrogen exchange



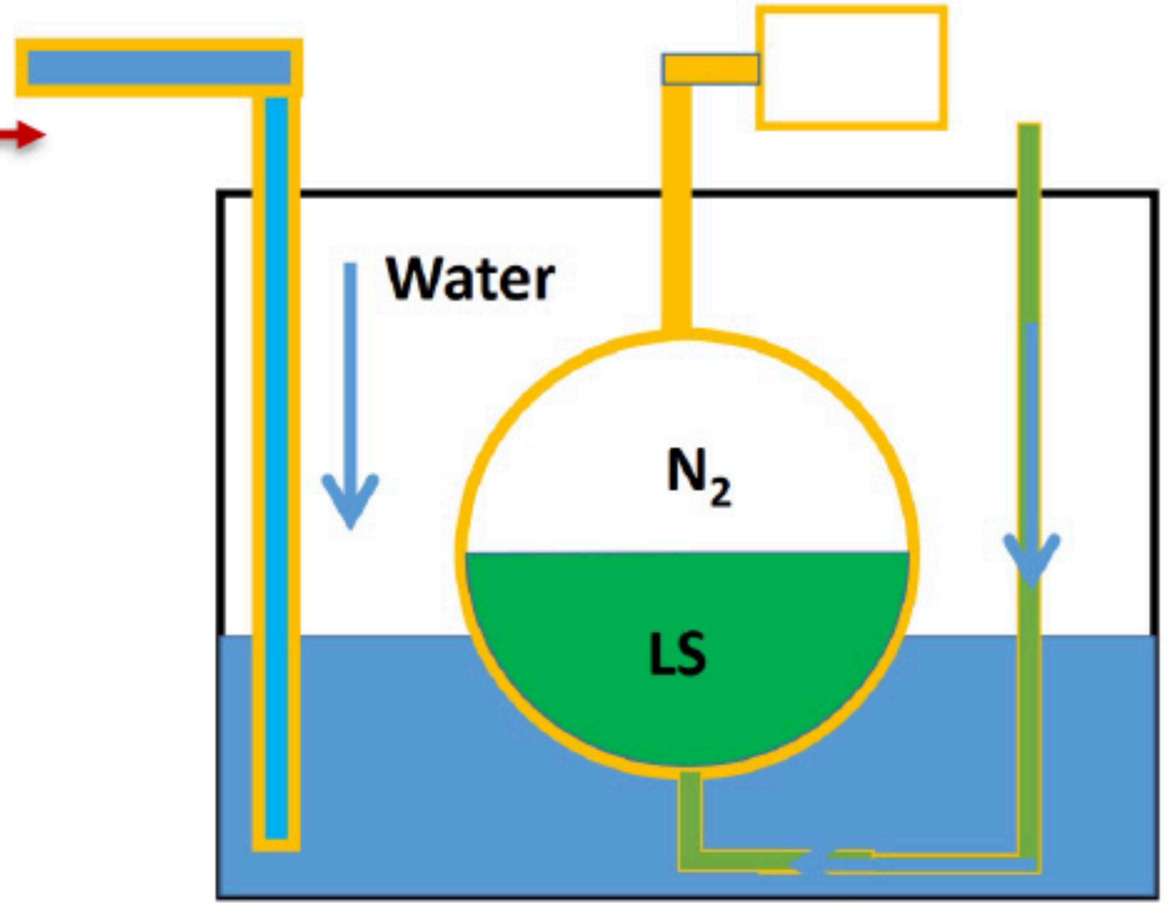
The detector filling

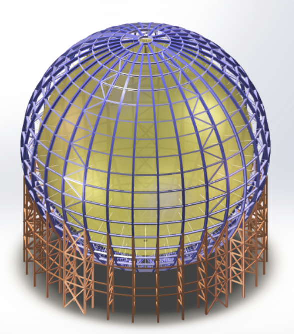
Two alternative choices

- Two filling schemes were both written in CDR. FDR/Tests on CD prototype/manufacturing were based on water exchange.
- Water exchange:
  - Firstly fill water into CD and water pool at the same time: **2 months**
  - Then fill in LS from top and drain out water from bottom : **6 months**



- N_2 exchange:
  - Firstly fill N_2 into CD with 10 - 20 volumes: **~ 24 days for 400 m^3/h or ~ 80 days for 200 m^3/h**
  - Then fill LS in to CD from bottom meanwhile fill water into water pool: **6 months**



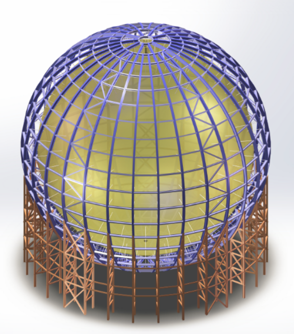


Past decisions

Results of previous reviews

1. In JUNO CDR, both water exchange and nitrogen exchange schemes for CD filling were proposed. The water exchange scheme is considered be safer both for people and equipment, and were adopted by Borexino and SNO. The FDR review based on water exchange was finished in January 2020

2. In January 2022, the decision was taken to switch to gas exchange, mainly because of the not clear partition factors between water and LS when they are in contact during the filling.



Past decisions

Results of previous reviews

	Water exchange	Gas exchange √
Background	2~3 orders too higher Ra Unknown Pb 2~5 times too higher Kr	Need to control Rn and Kr to the level of 1 mBq/m^3 and 50 μBq/m^3 , feasible
Time	2 months water filling + 6 months LS filling	1 month gas exchange (400 m^3/h) + 6 months LS filling
Upgrade	Yes	Yes
Safety	Safe	Risk to person

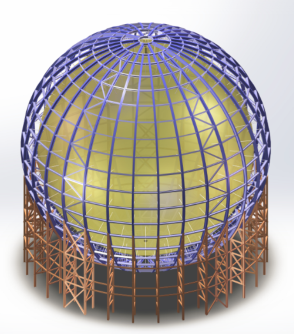
Conclusion of previous review

- From background risk, gas exchange is better than water exchange

BUT

Last ISC meeting

- Suggested by Stefen: hold discussions with SNO+ and KamLAND
- On March 17 and 28, we held meetings with SNO+(Mark Chen) and KamLAND (Kunio Inoue, Gando, and Kengo)

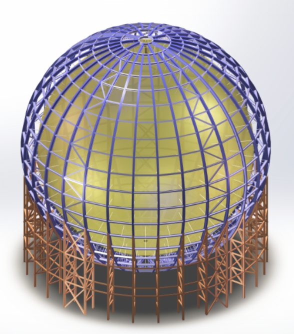


SNO+ and KamLAND meetings

Held in March 2022

- Very interesting discussions
- Most of the problems of both experiments come from Rn leaks into the pipes and the detector
- Partition factors between water and LAB experienced by SNO+ are much better than assumed in our previous calculations
- Both experiments experienced ^{210}Pb and ^{210}Po contaminations coming from the scintillator purification plant pipes

AND



Issues from the CD group

EB meeting - April 8, 2022

Risk Items	Worst Possible Results	Water Exchanging	Nitrogen Exchanging
Temperature field non-uniform and difficult to measure	Acrylic breaking	For 2 months when filling water, Need to control the big difference of temperature. For 6 months when filling LS, Water and LS have similar temperature about 21 ° C.	More dangerous For about 1+6 months when filling N_2 + filling LS and water, rock and PMT heat generation need to be balanced.
Pressure field non-uniform	Acrylic breaking	Less N_2 flush above LS	More dangerous
Testify LS quality	To answer when CD will be able to testify the LS quality	Filling LS after water shielding formed → • 50 tons of LS can be tested Okay or not, which is independent of OSIRIS • Pump out method is easy if LS is not good. Draining the LS from the top chimney while filling water from bottom chimney	More dangerous Filling LS and water same time, so no water shielding above the upper CD→ • Over thousands of LS filled with LS self shielding may be able to test LS quality (Or it may not because of the high PMT firing rate) • Too late to pump out • Pump out method is with risks also. Pipes begins from CD bottom chimney, then go through water pool gate with feedthrough, then with ISO tanks shipped out to above ground
Tests on prototype	If no control & safety testified→ • Unknown results • long term delay	2 round tests on prototype， half year spent → Function tests were done two years ago	Last minute changes, No prototype tests→ • Control system & safety interlock are difficult to test in real huge system within limited time, including pumps/valves/sensors/PLC program, very complicated
Bacteria in water	• Transparency of water • Transparency of acrylic (CD and PMT cover)	Fill N_2 into water pool while filling water → Danger for 2 months	More dangerous Fill N_2 into water pool while filling water and LS → Danger for 6 months, **<u>temperature / pressure / bacteria risks will be mixed. If anyone has problems, our experiment will lose.</u>**

The final decision

EB meeting - April 8, 2022

- **Back to water exchange scheme!**

			Effects on physics (partition factor 10^{-1} (U/Th/Pb) and 10^{-2} (Ra))		
	Radiopurity in water	Risk in LS	IBD	Solar (5y)	0νββ
^{238}U	10^{-15} g/g	0-1 orders too high	No	Be7: 0.2% (ideal) → 0.4% Pep: 5% (ideal) → 4% CNO: 4% (ideal) → 7%	2% bkg more
^{232}Th	10^{-15} g/g	0-1 orders too high			20% bkg more
^{226}Ra	40~1000 uBq/m^3	0~2 orders too high		-	2%~20% bkg more
^{210}Pb	10^{-21}~10^{-22} g/g	0~2 orders too high		For 2 orders Be7: 0.2% (ideal) → 1.1% Pep: 4% (ideal) → 5% CNO: 10% (ideal) → 17%	No
^{85}Kr	300 uBq/m^3	< 1 order		Be7: 0.2% → 0.7%	

New background estimates (work in progress)

Thanks for your attention!