A convenient approach to determine U/Th in acrylic to sub-ppt level

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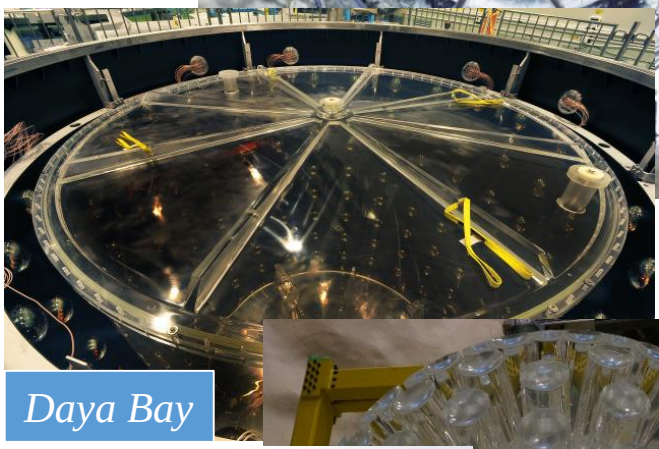
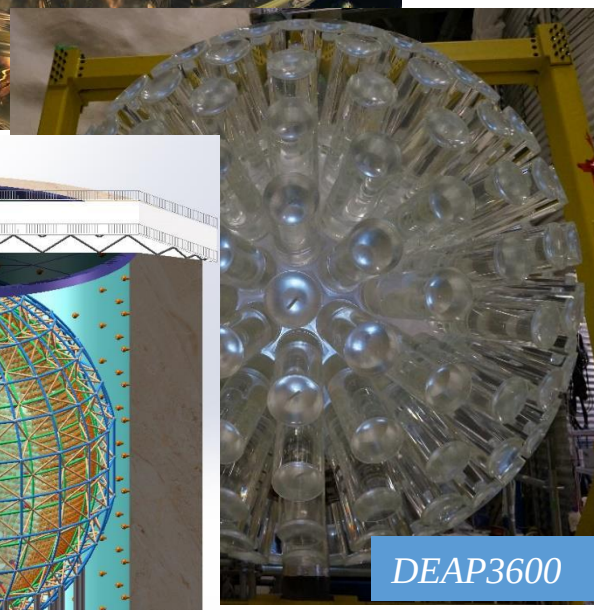
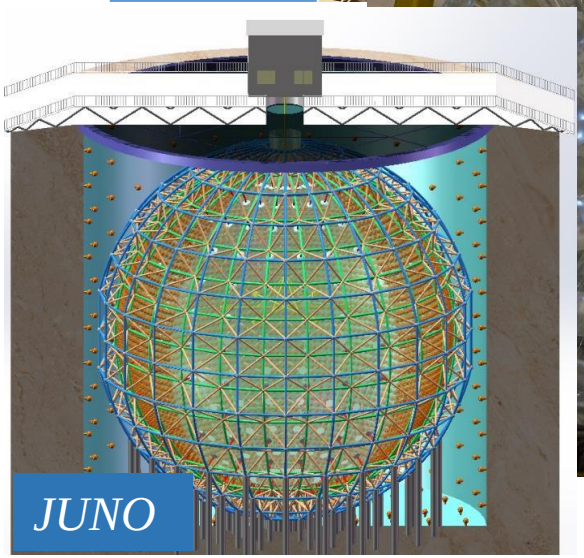
Acrylic in Neutrino/Dark Matter detectors

Experiments	Parameters
SNO	1000 t heavy-water / 6m radium 30t sphere vessel
Daya Bay	8 ×20t LS(Gd) / 1.5m radium vessel
DEAP3600	3.6t liquid Argon / 0.85m radium vessel
JUNO	20000t LS / 17m radium 566t sphere vessel

- Good light transmittance
  90-92% in air
- Good chemical compatibility
- Good mechanical strength
- Good Workability

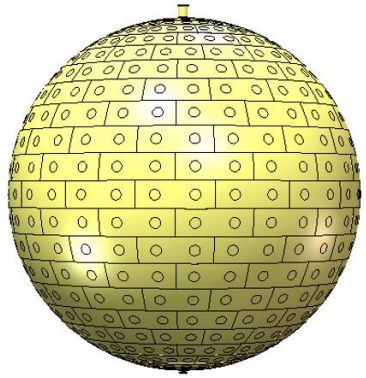






Widely used in dark matter and neutrino experiment

Radioactivity Requirement



- Requirement of acrylic in different experiment

	U238	Th232
SNO	7ppt	2ppt
DEAP3600	0.3ppt	1.3ppt
JUNO	1ppt	1ppt

ppt:10^{-12}g/g

JUNO has a 566t acrylic sphere made of over 600 pieces. A highly sensitive and fast approach to measure U/Th in acrylic is desired to control the background in production.

Methods for ppt U/Th level measurement of acrylic

	Acrylic mass	Sensitivity (U/Th)	Experiment	Ref.
NAA + HPGe	~ 20 g	<0.5 ppt	Milano Bicocca	[1]
PMMA vaporization + Alpha spectroscopy	~25kg	<1 ppt	SNOLAB	[2]
PMMA vaporization + HPGe	~10kg	<1 ppt	SNO&DEAP3600	[3]
PMMA vaporization + ICP-MS	~5kg	<1 ppt	SNOLAB	[2]

[1] Monica S., "Review on Neutron Activation Analysis"https://indico.cern.ch/event/716552/sessions/310934/attachments/1848163/3033363/MonicaSisti_LRT2019.pdf Retrieved 11 May 2019
[2] Earle, E.D., Deal, R., Gaudette, E., Polycast Acrylic Sheets (SNO Communication). Jan. 24 1994. SNO-STR-93-042
[3] Corina, M.N. Radiopurity measurement of acrylic for the DEAP-3600 dark matter experiment. Jan. 22 2014.

Measuring instrument

- ICP-MS
  - Super high sensitivity
  - Fast measurement
- Difficulties
  - How to get proper samples can be tested by ICP-MS
  - Contamination in sample preparation
- Pretreatment Strategies:
  1. ~~Dissolving acrylic directly~~

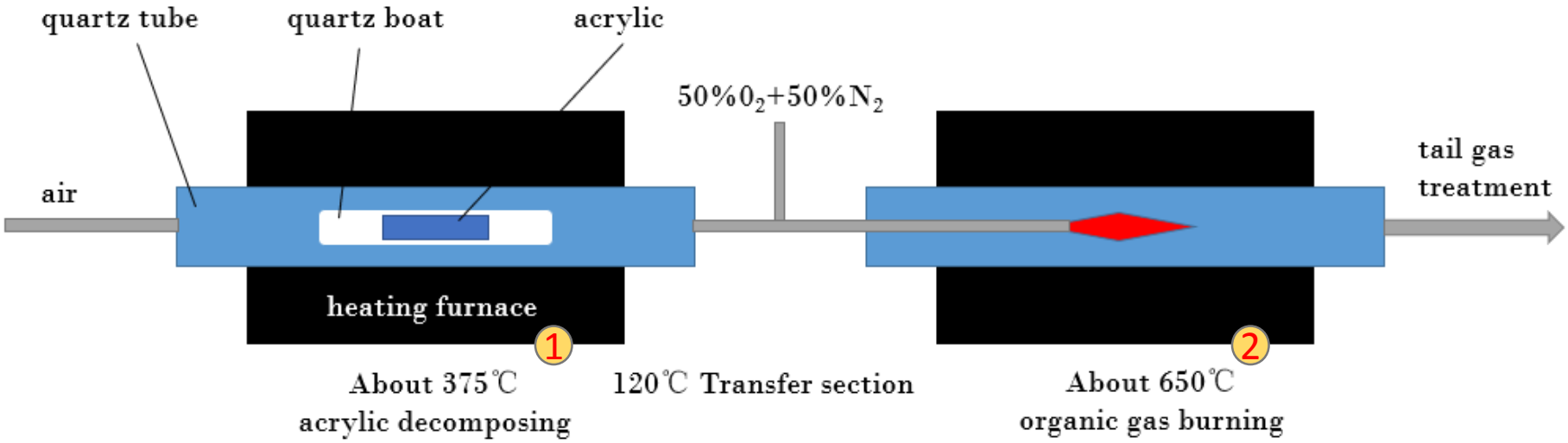
     Contamination from pretreatment (micro-wave digestion) is several ppt
  2. Vaporizing acrylic and dissolving U/Th

     No organic component left

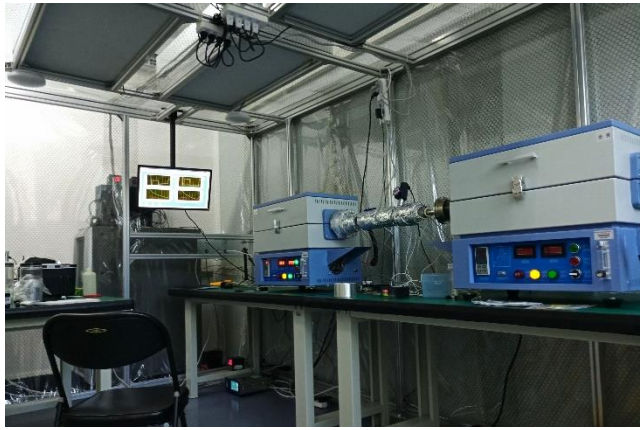
     U/Th concentrated

ICP-MS

Acrylic decomposition equipment

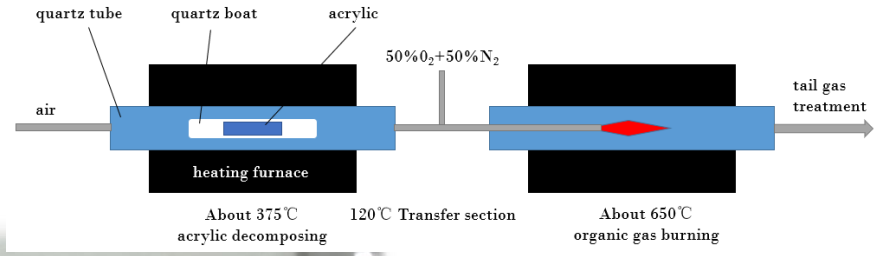


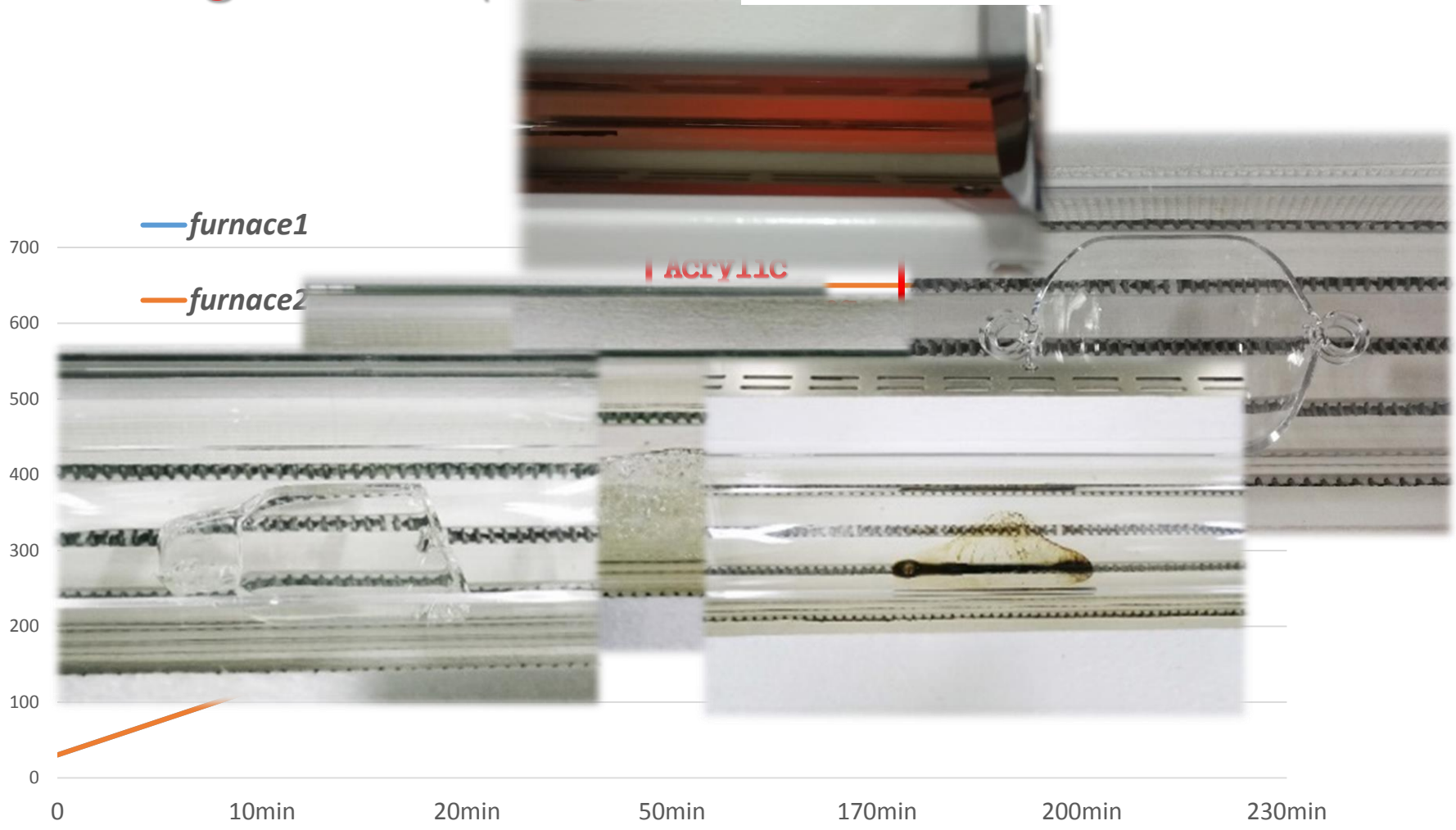
Schematic diagram



- Furnace1 for decomposing the acrylic
- Furnace2 for burning the organic gas from furnace1

Heating Process(15g×3)





Tests on ICP-MS

- Collection efficiency calibration
- Blank test
- U/Th concentration of acrylic

Collection efficiency calibration

- Using ^{229}Th solution (2%HNO_3) as the standard solution to do recovery efficiency test

  Not exist in nature

- Background from ^{229}Th solution

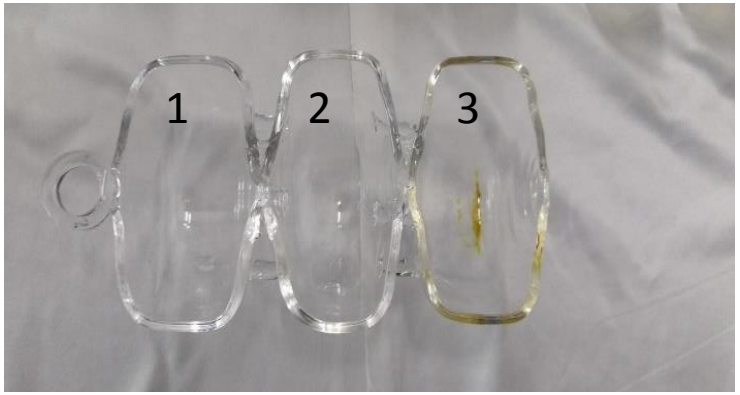
Unit: ppt	^{238}U	^{232}Th
0.2 ppt Th229	0.02±0.01	0.03±0.01
1 ppt Th229	0.04±0.01	0.10±0.01

- Collection efficiency test: ~60% for acrylic (tested every time)

	0	1	2	3	4	…
eff. ^{229}Th	36.2±0.4	65.6±0.6	69.7±1.0	60.9±1.3	88.7±4.7	…

10 seconds ➡ 3mins ×3

Blank test



Quartz boat

Contamination sources

- Quartz boat
- ^{229}Th solution
- Sampling liquid (2% ultra pure HNO_3 solution)
- Residue collecting operation
- …

Unit: ppt	^{238}U	^{232}Th
No.1	0.04±0.01	0.03±0.01
No.2	0.04±0.01	0.03±0.01
No.3	0.05±0.01	0.02±0.01

Blank test for quartz boat

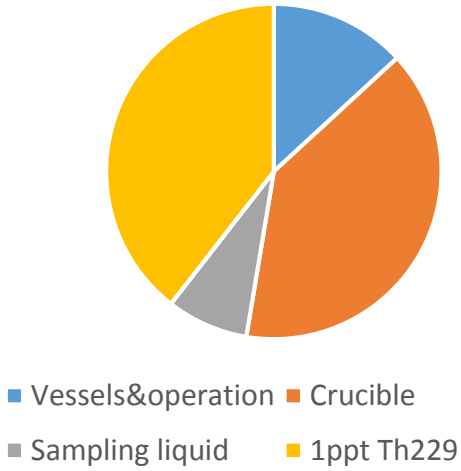
^{238}U	^{232}Th
<0.01ppt	<0.01ppt

Blank test for 2% ultra pure HNO_3 solution

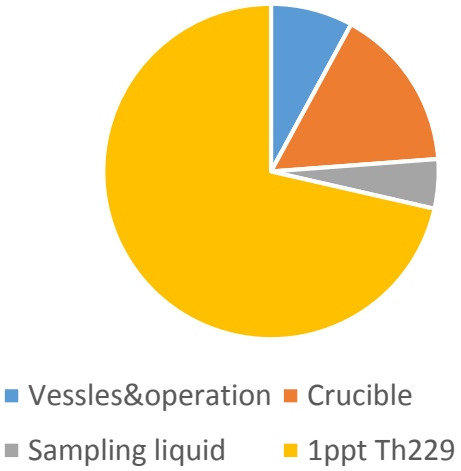
Background level

Contamination Sources		^{238}U(ppt)	^{232}Th(ppt)
No.1	PFA vessel, 2% HNO_3, Transferpettor	0.01±0.01	0.01±0.01
No.2	No.1 & Crucible	0.04±0.02	0.04±0.02
No.3	No.1 & 0.2ppt ^{229}Th std	0.02±0.01	0.03±0.01
No.4	No.1 & 1ppt ^{229}Th std	0.04±0.01	0.10±0.01

^{238}U contribution



^{232}Th contribution



Most of the background comes from ^{229}Th tracer agent

U/Th content of acrylic

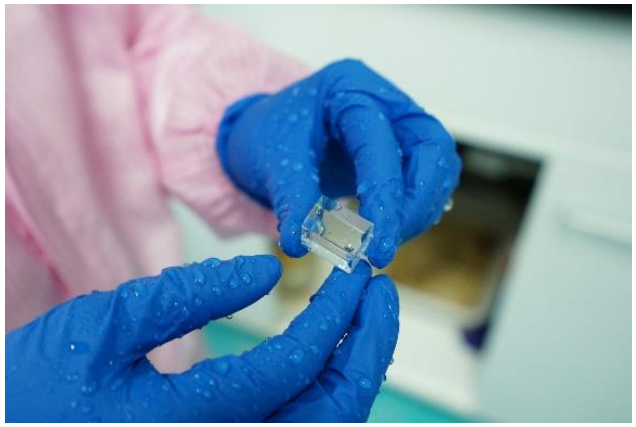
$$\text{Result} = (B - C)/\text{eff.} - A$$

A:U/Th from vessels/sampling liquid/crucible

B:acrylic

C:^{229}Th solution

eff.: collection efficiency



Result: Blank and collection efficiency are corrected

Unit: ppt	^{238}U	^{232}Th
No.1 unwashed normal acrylic	3.17±0.16	6.93±0.47
No.2 washed normal acrylic	1.35±0.12	3.64±0.24
No.3 potential candidate for JUNO	0.29±0.05	0.54±0.18

Summary

- A convenient method for sub-ppt $^{238}U/^{232}Th$ acrylic measurement is developed
  - Background level ~ 0.1ppt
  - Sensitivity <1ppt
  - Quick testing 1~2 days per sample

- Application
  - Extend to other organic materials
  - Plan to use this method in batch quality test for JUNO

Thank you!