Low background study for AMoRE through material screening facility at Y2L and Yemilab

Low Radioactivity Techniques 2022

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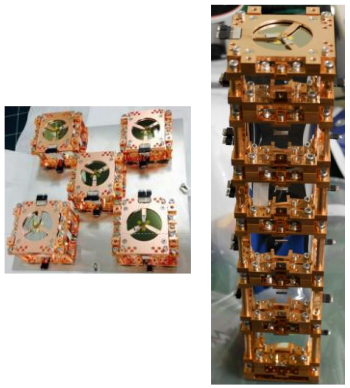
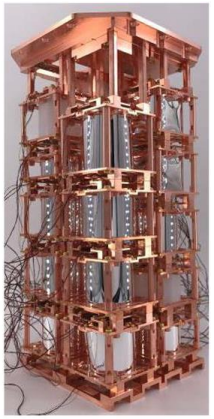
On behalf of the AMoRE Collaboration

CENTER FOR UNDERGROUND PHYSICS

AMoRE experiment

	Pilot	AMoRE-I	AMoRE-II
^{100}Mo Q-value (3034 keV) Natural abundance (9.7%) Enriched up to 96%			
Crystal	$^{40}Ca^{100}MoO_4$	$(^{40}Ca,Li_2)^{100}MoO_4$	$Li_2{}^{100}MoO_4$
Crystal Mass (kg)	1.9	6.2	~180
Background Goal (ckky)	0.37	$<10^{-2}$	$<10^{-5}$
$T_{1/2}$ (year)	3.4×10^{23}	7.0×10^{24}	8.0×10^{26}
$M_{\beta\beta}$ (meV)	1200-2100[1]	140-270	13-23
Schedule	2016-2018	2020-2022	2023-2027

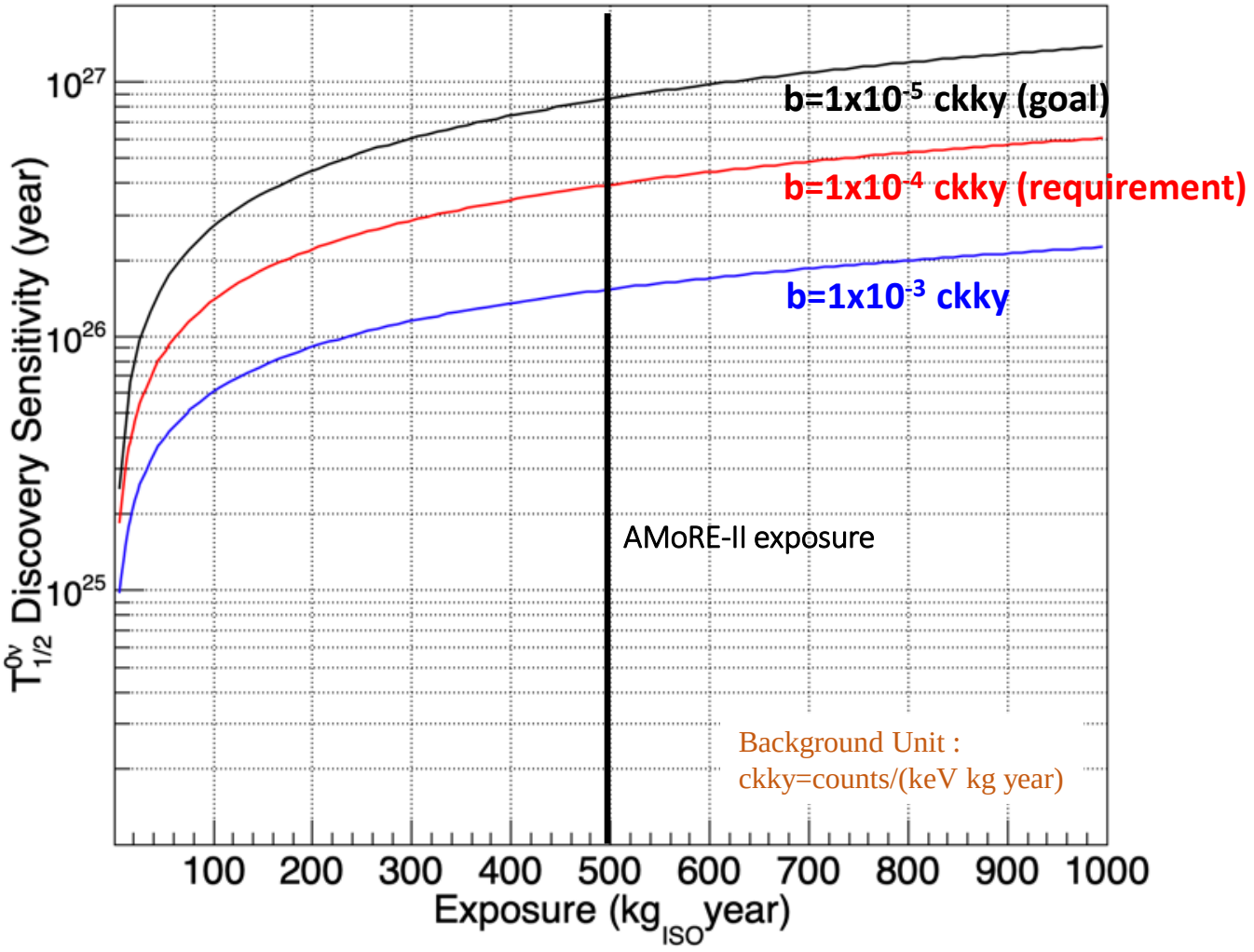
[AMoRE Experiment]

- The AMoRE is an experiment to search for 0νββ decay of ^{100}Mo using molybdate scintillation crystals.
- The 1st phase, AMoRE-I, using about 6 kg of crystals is ongoing in Y2L (Yangyang underground laboratory).
- The 2nd phase, AMoRE-II, will be operating at the Yemilab, which is a new underground laboratory of CUP, using about 180 kg of LMO crystals.

Sensitivity for AMoRE-II

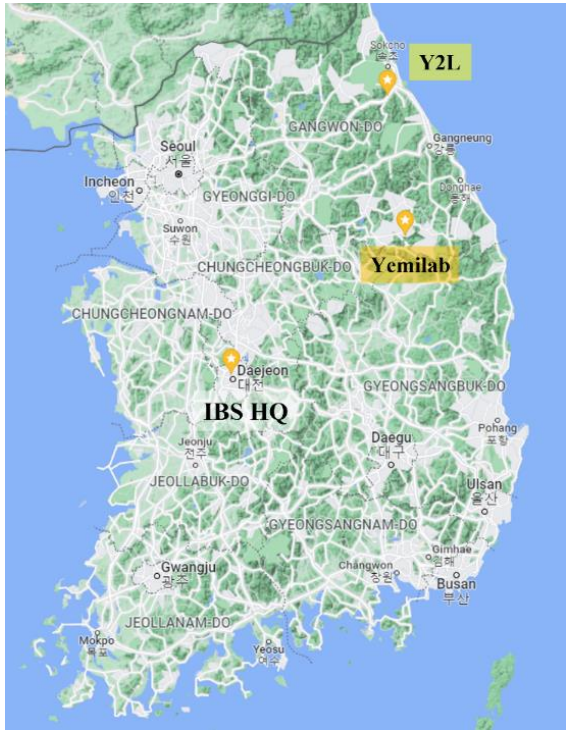
- Discovery sensitivities depend on background and exposure
- AMoRE-II time schedule: 2023~2027 (5 years)
- Background requirement: ~10^{-4} ckky / goal : ~10^{-5} ckky

Discovery sensitivity with a significance of at least 3 sigma (99.7%).

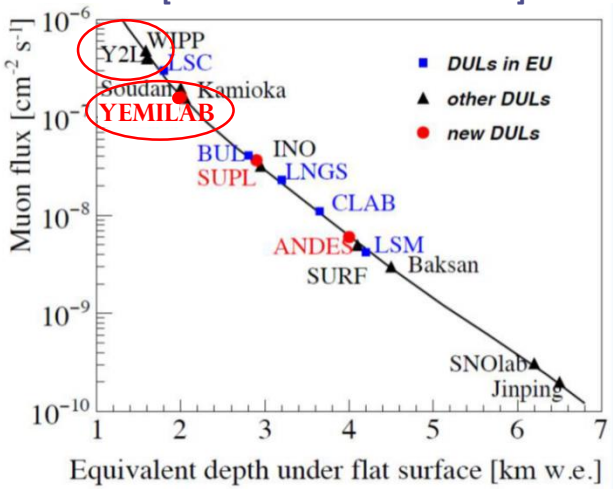


Underground Laboratories of CUP

	Y2L (2003~)	Yemilab (2022~)
Location	Yangyang	Jeongseon
Depth (m)	700	1000
Area (m^2)	350	~3000
Rock Radioactivity (ppm)	U: 3.9(14) Th: 10.5(65) K: 40000	U: 0.8(3) Th: 3.3(4) K: 11800
Experiments	**AMoRE-I** COSINE-100	**AMoRE-II** COSINE-200 IsoDAR(?)

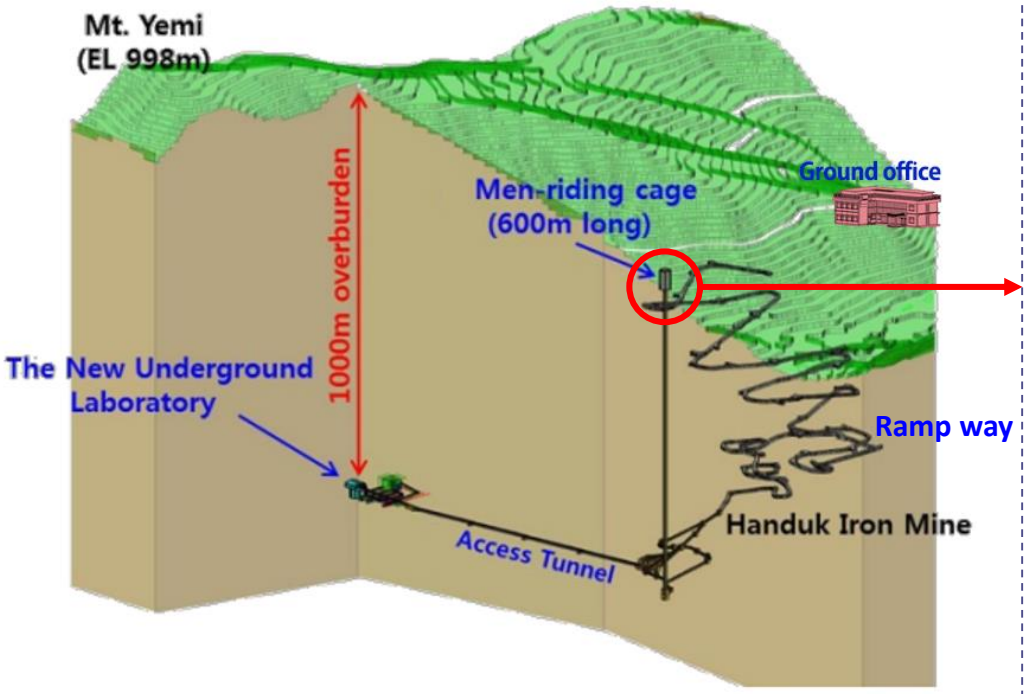


[Location of Y2L & Yemilab]



[Muon flux of underground laboratories]

Yemilab [2]

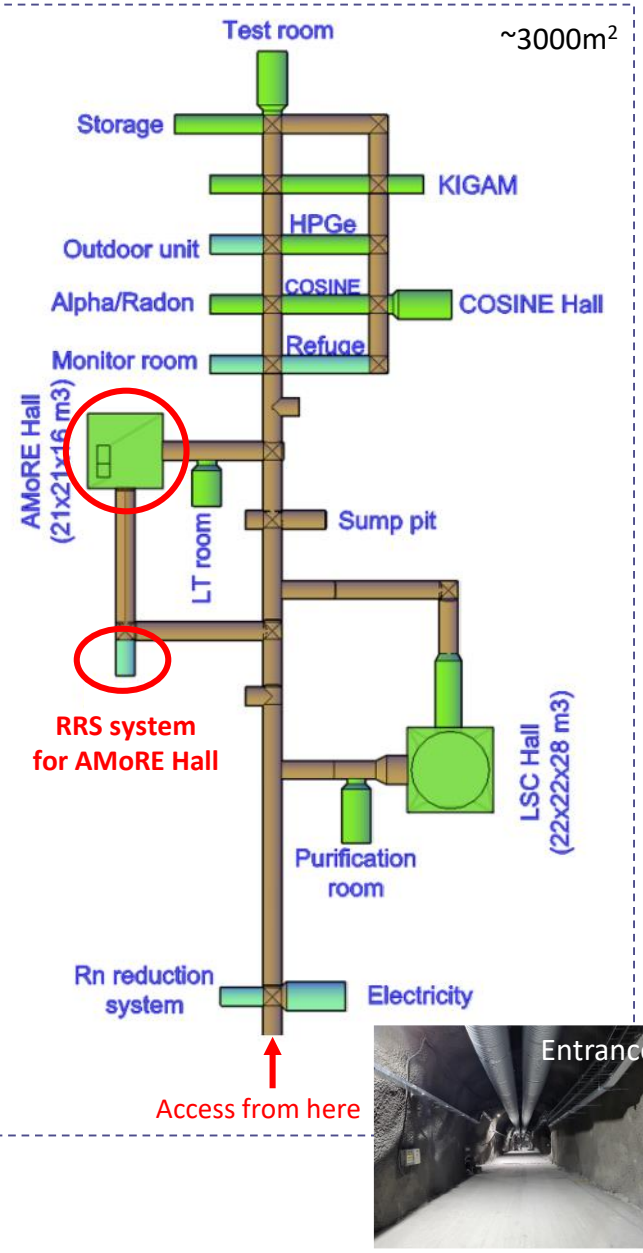


[Man cage]

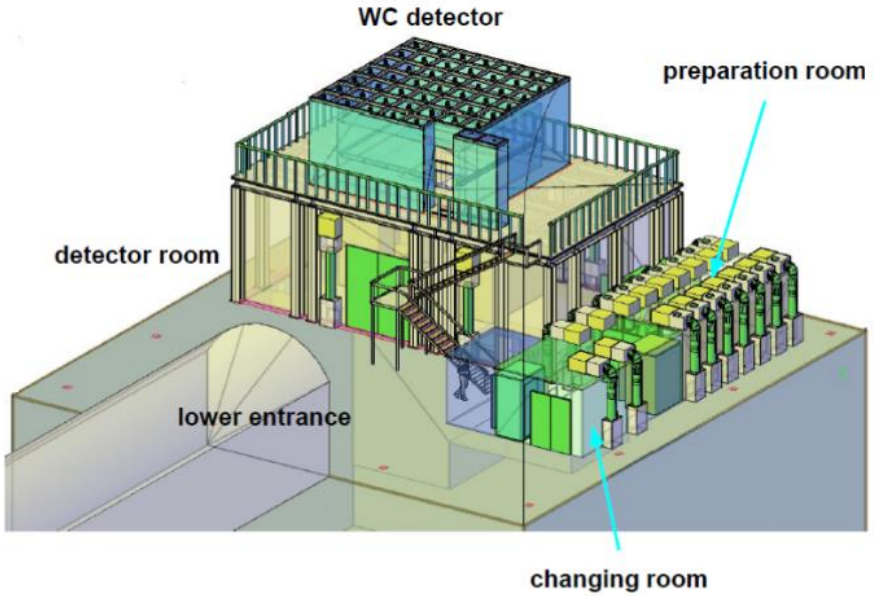
- Location: underground tunnel next to the Handuk iron mine at Jeongseon, Gangwon-do, South Korea.
- Access tunnel: 782 m long with 12% downslope
- Man cage: 587 m vertical moving, 2.5 min to the underground, 1.5 ton payload, maximum 5 persons allowed at once

Yemilab construction

[Yemilab drawing]



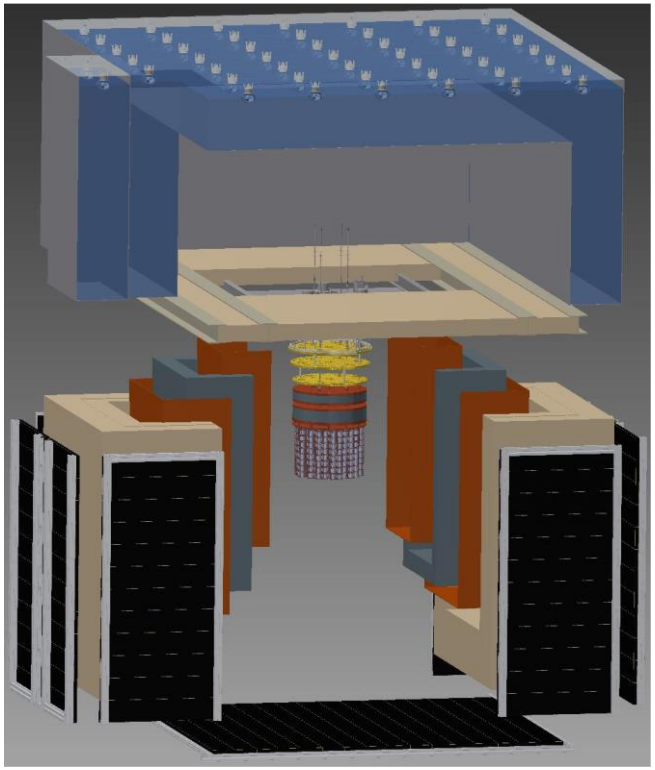
[overview of AMoRE Hall construction]

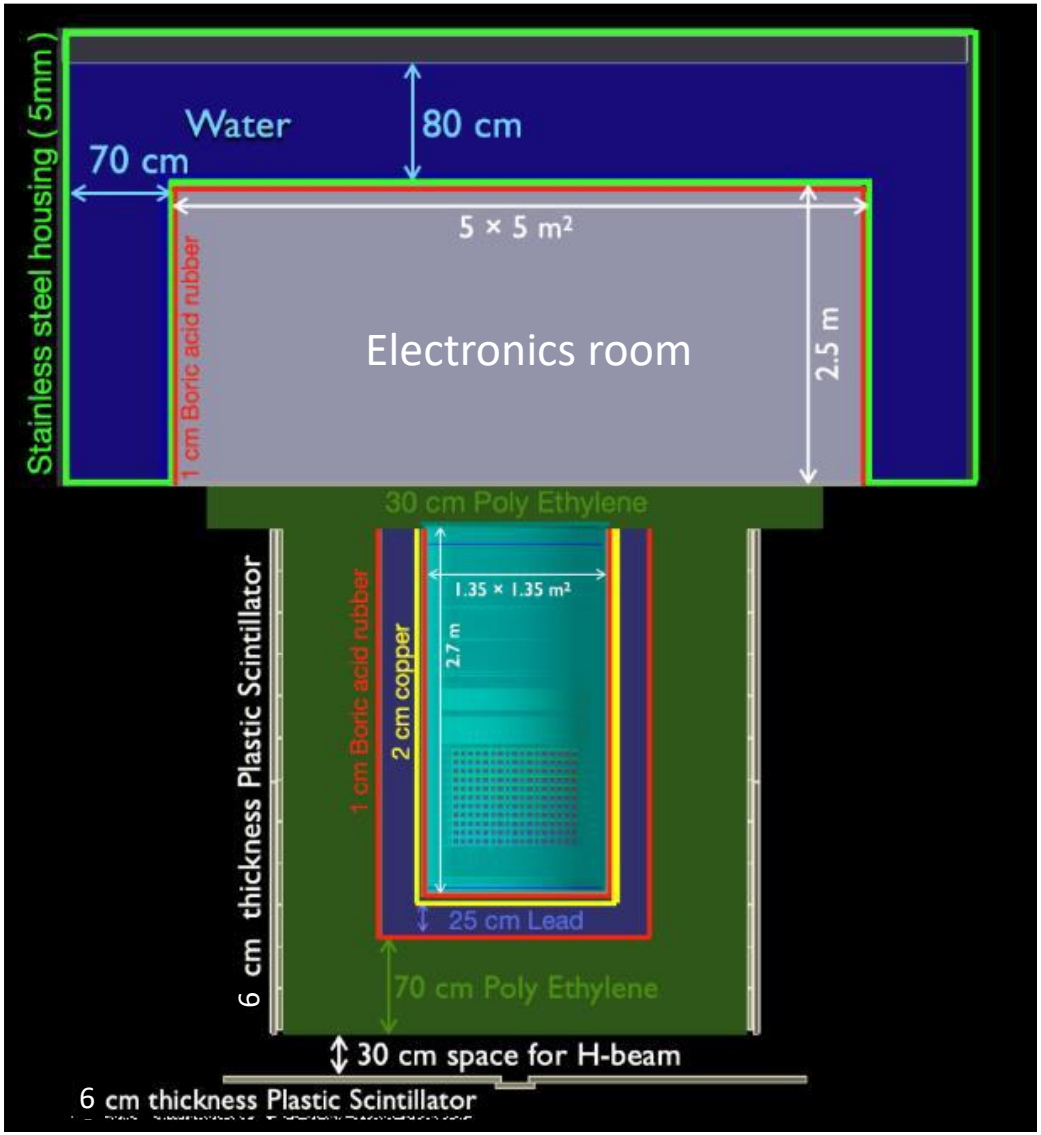


Radon **R**eduction **S**ystem (RRS) for AMoRE Hall

- target level : ~20 mBq/m^3
- supply capacity : 50 m^3/h
- No PCW requirement
- Humidity < 2000 ppm

AMoRE-II shielding system



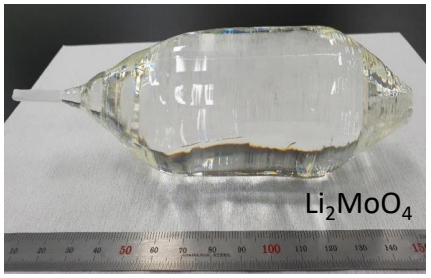


[inner] [outer]

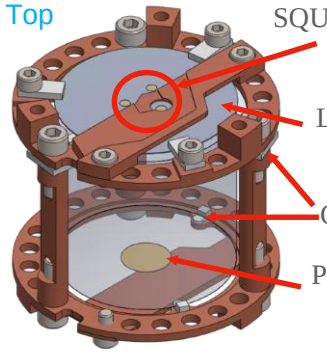
1cm Boric acid rubber → 2cm Copper → 25cm Lead → 1cm Boric acid rubber → polyethylene

Crystal & Detector module for AMoRE-II

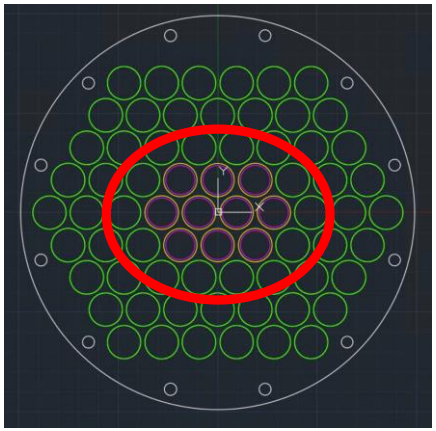
[crystal growing in IBS HQ]

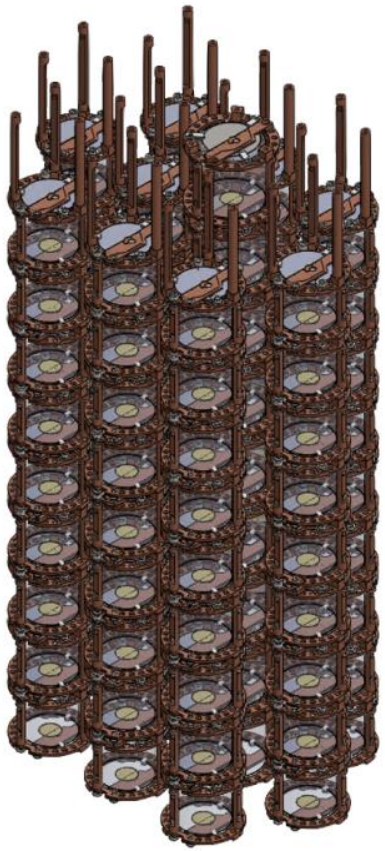


Purified Li_2Co_3 and MoO_3 powders are used



[Detector module]





[Tower of 90 crystals for the first stage]

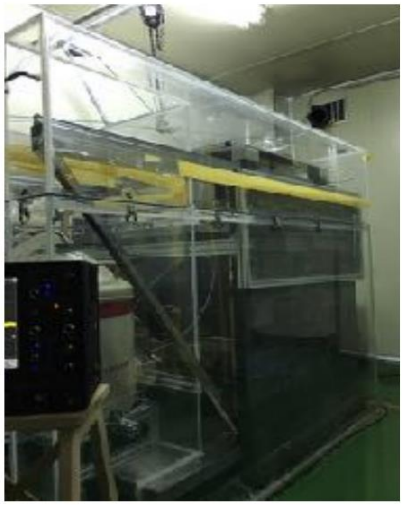
- 1st stage of AMoRE-II : 90 crystals (~27 kg), will be started in 2023
- 2nd stage of AMoRE-II : ~600 crystals (~180 kg)

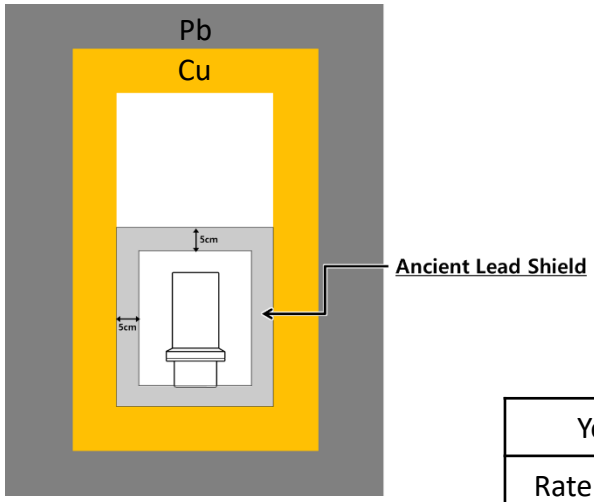
Material screening facilities[3]

- Facilities
  - 2 single HPGe detectors (CC1, CC2) at Y2L
  - An array of 14 HPGe detectors (CAGe) at Y2L
  - An ionization alpha counter at Y2L
  - ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) at IBS HQ (Deajeon)

- Cross check between different methods

HPGe detectors: single detectors [4]

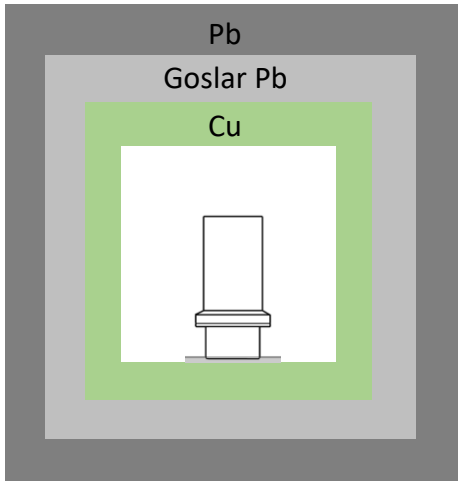




CC1 (2010~)

- Relative efficiency: 100%
- Dedicated shielding system
  - Top & bottom: Pb 10cm + Cu 10cm
  - side: Pb15cm + Cu 10cm
  - innermost: Ukraine Ancient Pb 5cm
- Background count rate (50~4000 keV)

Year	2015	2018	2019	2020	2021
Rate (mHz)	8.1	7.9	7.8	7.9	8.0



CC2 (2016~)

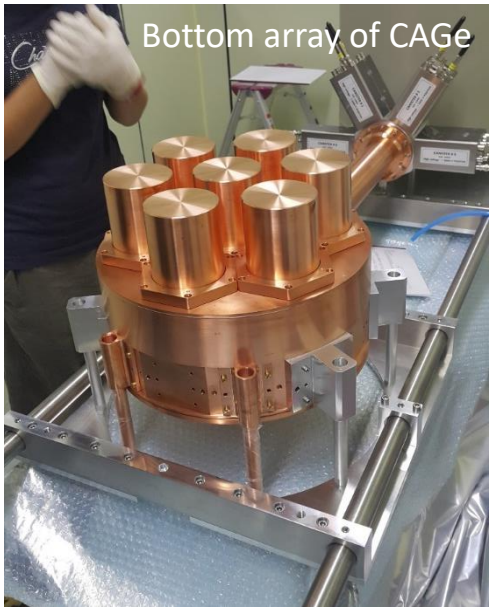
- Relative efficiency: 100%
- Dedicated shielding system
  - Cu 10cm + Goslar Pb 10cm + Pb 10cm
- Background count rate (50~4000 keV)

Year	2017	2018	2019	2020	2021
Rate (mHz)	9.5	7.9	6.8	6.2	6.1

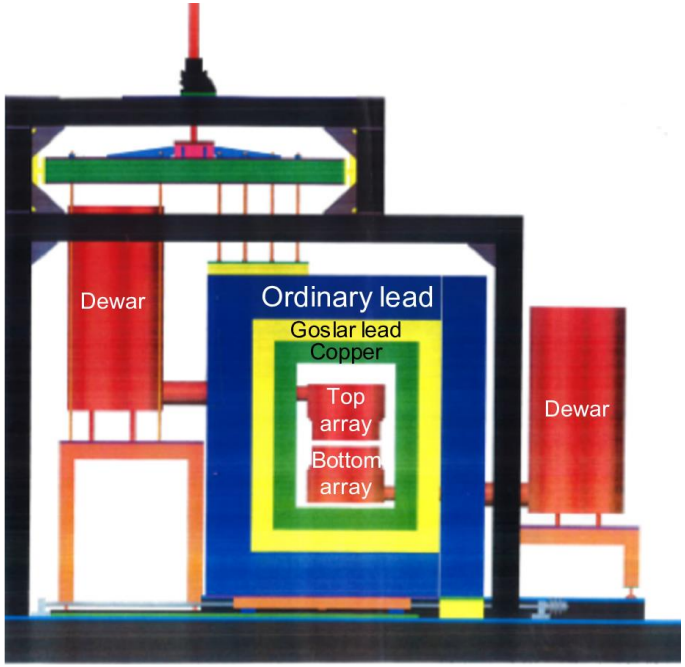
HPGe detectors: CAGe [5-7]

- CAGe (CUP Array of Germanium) is an array of 14 HPGe detectors for high sensitivity measurement
- Location: Y2L
- Relative efficiency: 70% each
- Shielding system: 5cm Cu + 5cm Goslar Pb + 10cm Pb
- Background rate (2021)
  - single hit : 90.4 ± 0.3 [event/kg/day]
  - double hit : 5.74 ± 0.07 [event/kg/day]

[CAGe]



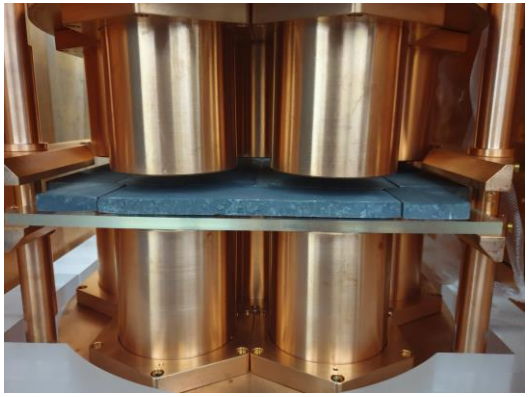
[shielding structure]



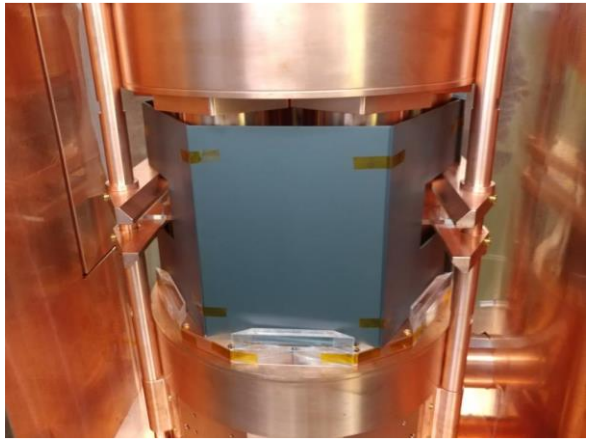
HPGe detectors: CAGe

- Low background material screening: materials for AMoRE construction (lead, copper, etc), MoO_3 powder for crystal growing
- Rare event physics research: 2νββ decay of ^{100}Mo, decay of ^{180m}Ta, decay of ^{50}V

[MoO3 powder]



[lead]



[Tantalum]

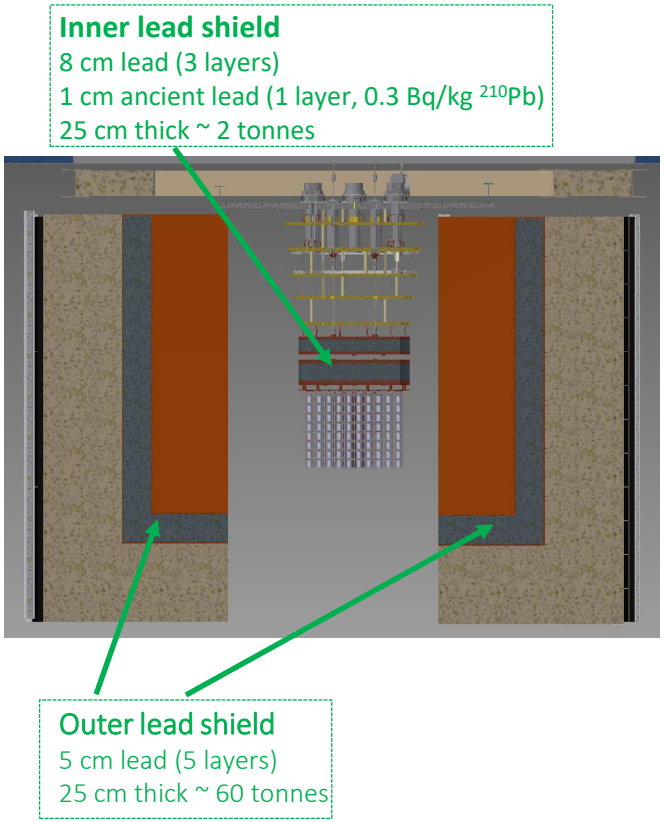
Lead issue for AMoRE-II [8]

- We found that the low background lead from Goslar company is not available anymore at the year 2021.
- Even it is available in another company, the cost is high (about 50k$ per ton)

[^{214}Bi High E gamma]

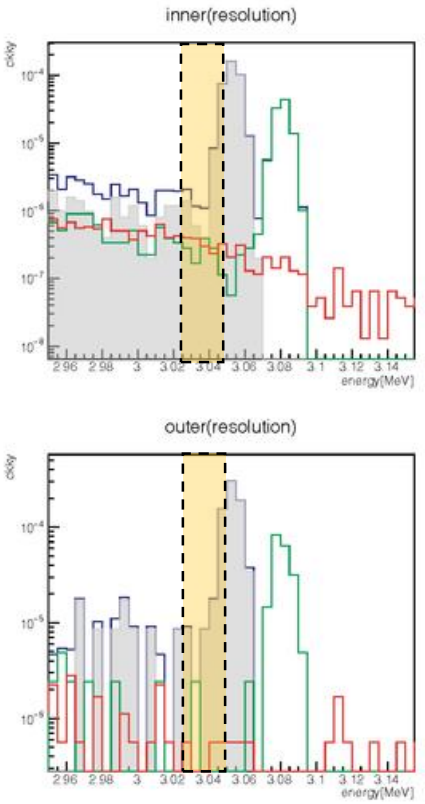
E (keV)	Branching (%)
2694.66(13)	0.0300(14)
2769.92(15)	0.0245(14)
2785.93(15)	0.0055(5)
2880.35(14)	0.0100(14)
2893.59(14)	0.0059(5)
2921.97(15)	0.0136(9)
2940.0	0.0036(14)
2978.94(15)	0.0136(5)
3000.0(2)	0.0086(9)
3053.9(2)	0.0209(23)
3081.79(25)	0.0059(18)
3142.6(4)	0.00123(4)
3183.6(4)	0.00136(23)

[Lead parts of AMoRE-II shielding]



Simulation

10 ppt (~0.12 mBq/kg) of ^{214}Bi
FWHM resolution : 10 keV



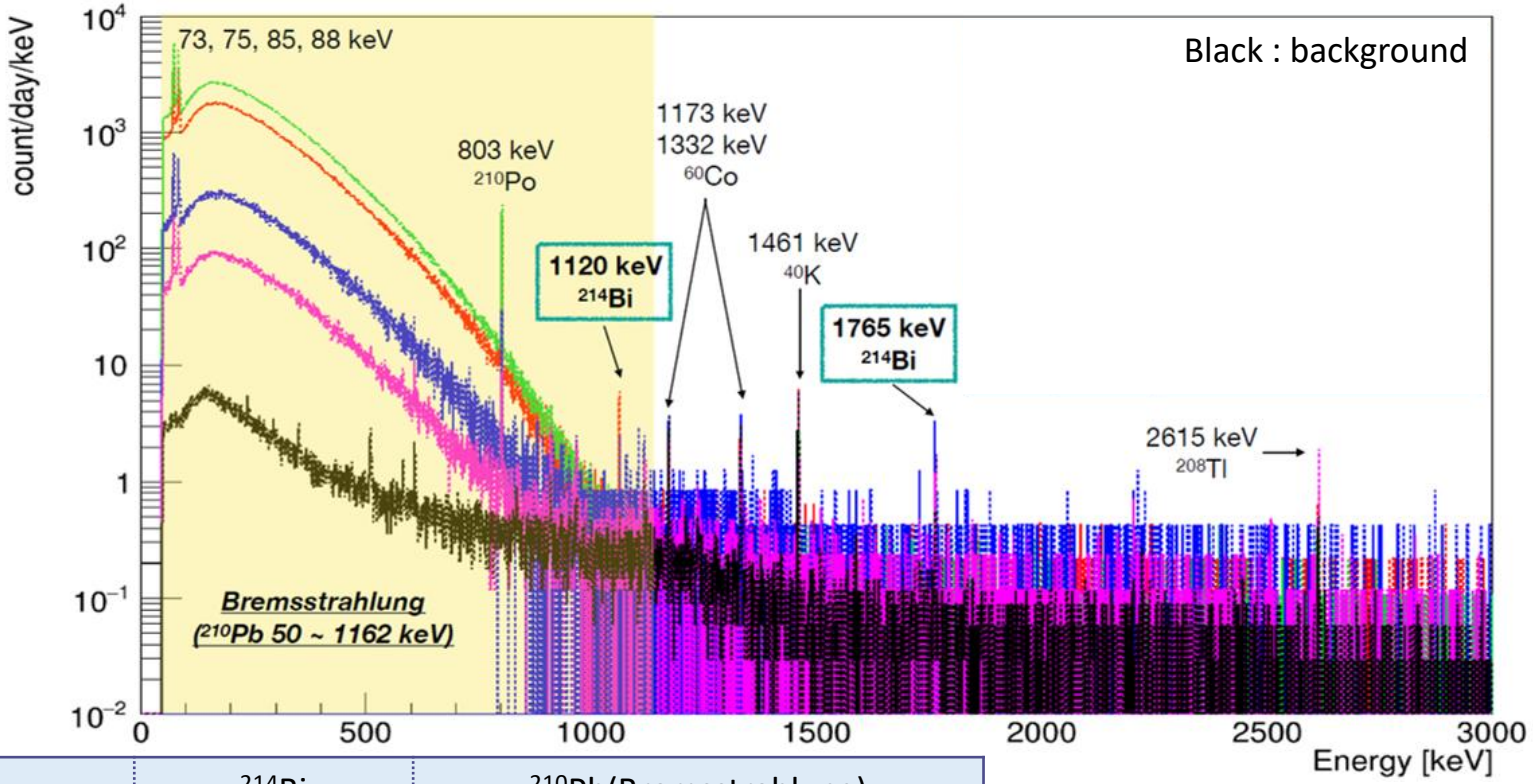
^{214}Bi

- ROI of AMoRE-II : 3034 ± 10 keV
- Depending on energy resolution, 3054 keV signals can be merged. (effect is negligible with energy resolution FWHM < 5 keV)
- Required levels of ^{214}Bi for the lead shields : **Inner part < 0.9 mBq/kg, outer part < 0.3 mBq/kg**

^{210}Pb

- High ^{210}Pb activity level can make noise at ROI because of random coincidence.
- According to simulation, Bremsstrahlung level requirement is < 50 Bq/kg

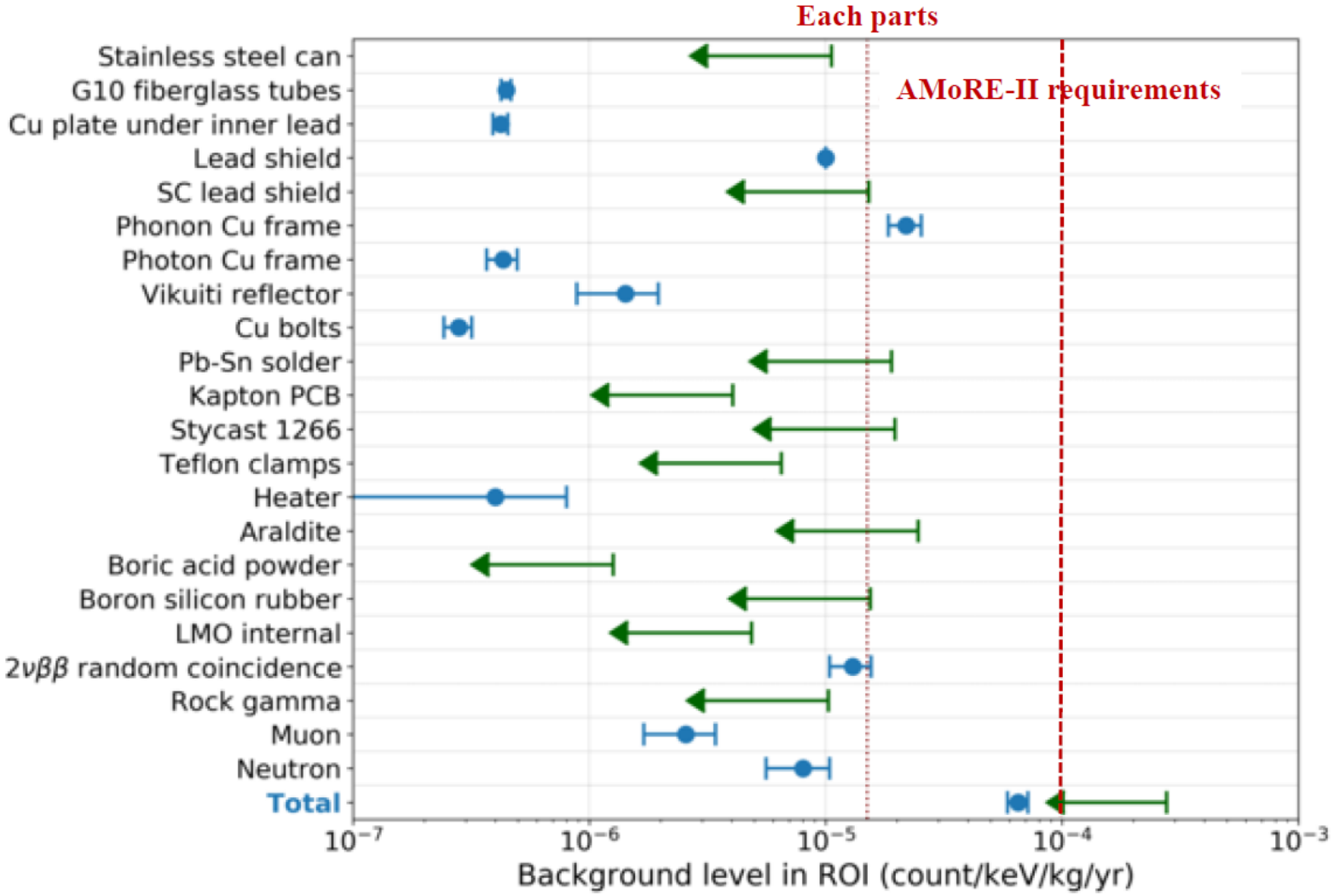
Lead issue for AMoRE-II



Company	^{214}Bi [mBq/kg]	^{210}Pb(Bremsstrahlung) [Bq/kg]
A(Korea)	< 0.44	~850 Bq/kg (Relatively estimated)
B(Korea)	< 0.61	~600 Bq/kg (Relatively estimated)
C(Korea)	Analysis ongoing	~100 Bq/kg (Relatively estimated)
Goslar	0.41(10)	30(1) Bq/kg (Alpha counter, 2015)
Boliden	Measurement ongoing	

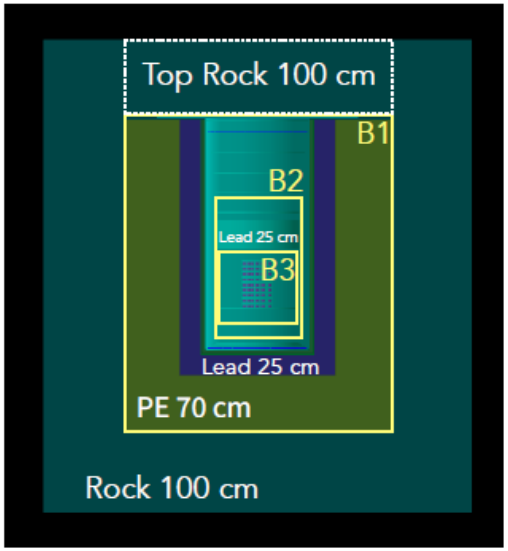
- It is confirmed that A, B, and C leads can not be used for AMoRE-II shielding because of high ^{210}Pb level.
- For ^{214}Bi level, the sensitivity of CAGe barely reaches to the AMoRE-II requirement for the outer leads which is less than 0.3 mBq/kg

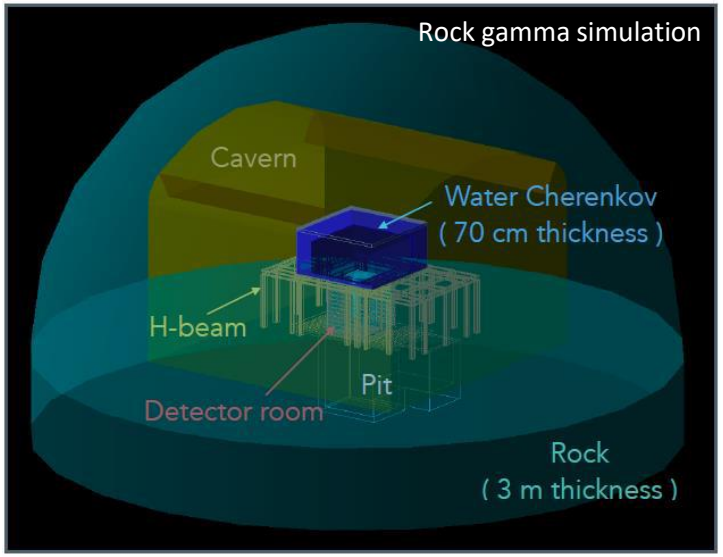
AMoRE-II background estimation[9]

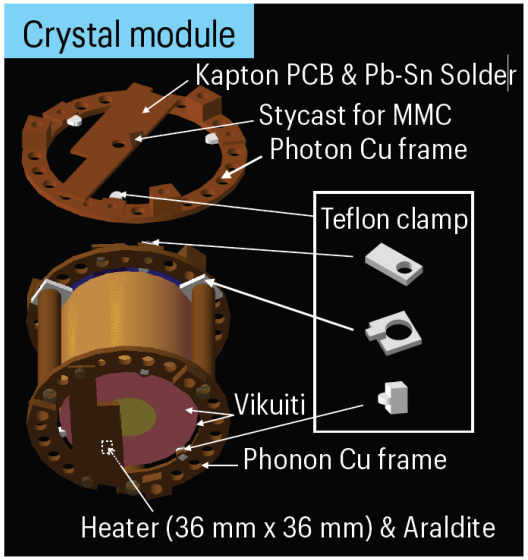


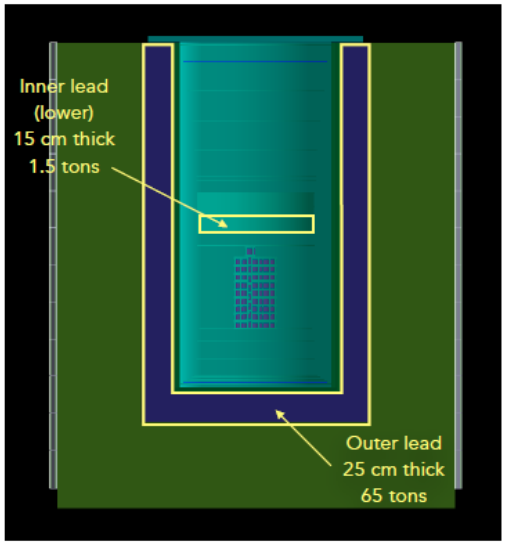
- Lots of samples have been measured
- all components still meet our requirements
- Continued for future experiments

Simulation study for background level of AMoRE-II [10]









BG sources	BG in ROI (x 10^{-5} counts/keV kg yr)
Cosmic muons	0.275 ± 0.0159
Radiogenic neutrons	0.301 ± 0.0107
Rock gammas (^{238}U)	< 1.03 (90% C.L.)
Lead Shield (^{238}U)	0.994 ± 0.0495
Clamps	0.65
Total	**3.25 ± 0.0761**

Summary

- The AMoRE is an experiment to search for 0νββ decay of ^{100}Mo using low-temperature molybdate-based scintillation bolometers. AMoRE-I uses about 6 kg of molybdate crystals is ongoing in Y2L. The large scale AMoRE-II experiment, will be operating at the Yemilab using about 180 kg of crystals.
- Two single HPGe detectors, CAGe, an alpha counter, and an ICP-MS are operating to measure radioactivity for low background study. Most of the AMoRE-II materials are cross-checked by different methods (alpha-, gamma-spectrometry, and ICM-MS).
- Background level requirement for AMoRE-ll is ~10^{-4} ckky, and all the analysed components are meet our requirements. More material screening and simulation studies will be continue.

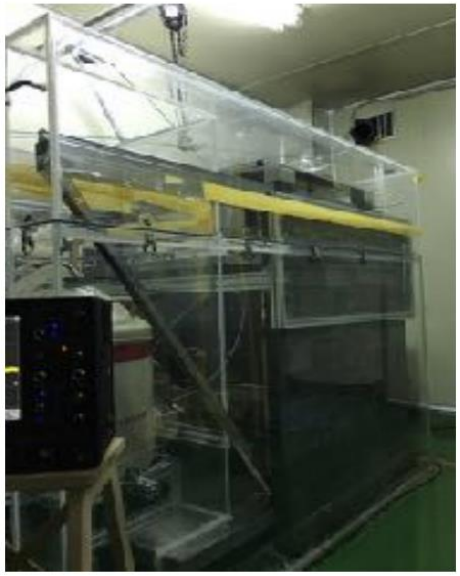
[Ref]

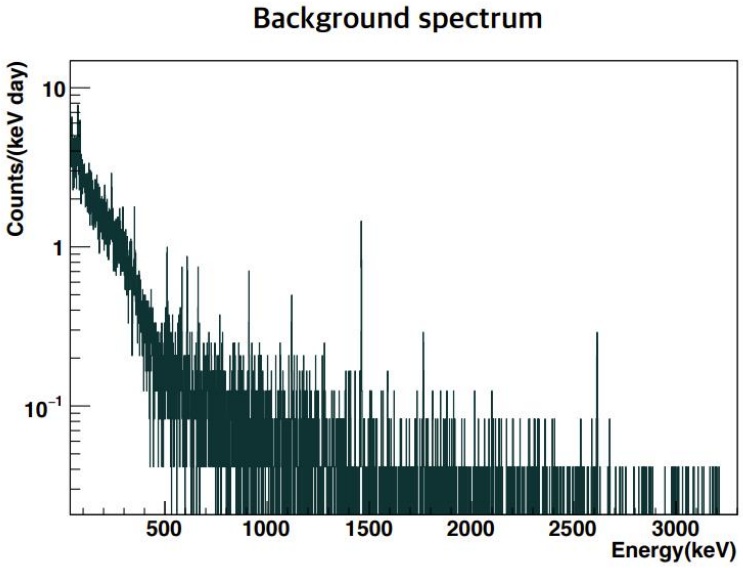
[1] V. Alenkov *et al.*, Eur. Phys. J. C 79 (2019) 791
[2] K.S. Park *et al.*, J. Phys.: Conf. Ser. 2156 (2022) 012171
[3] M.H. Lee, J. Phys.: Conf. Ser. 1468 (2020) 012249
[4] E.K. Lee 2022 poster @ ICRM 2022
[5] S.Y. Park *et al*, NIMA 992 (2021) 165020
[6] E. Sala *et al*, J. Phys.: Conf. Ser. 718 (2016) 062050
[7] D.S. Leonard *et al.*, NIMA 989 (2021) 164954
[8] S.Y. Park presentation @ 2022 KPS spring meeting
[9] J.H. So, presentation @ The 7th Symposium on Neutrinos and Dark Matter in Nuclear Physics (2022)
[10] J.W. Seo, poster @ NEUTRINO 2022

BACK UP

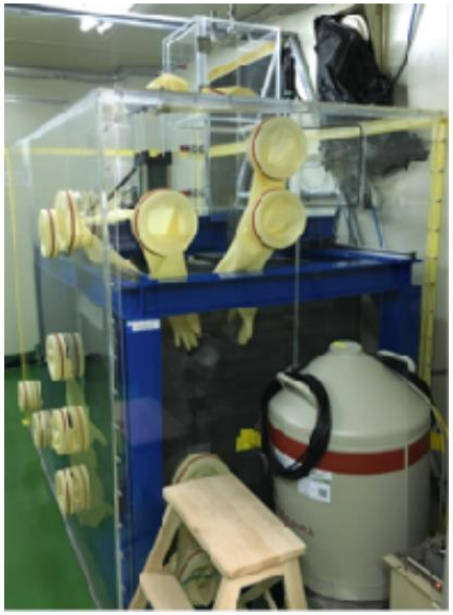
HPGe detectors: single detectors

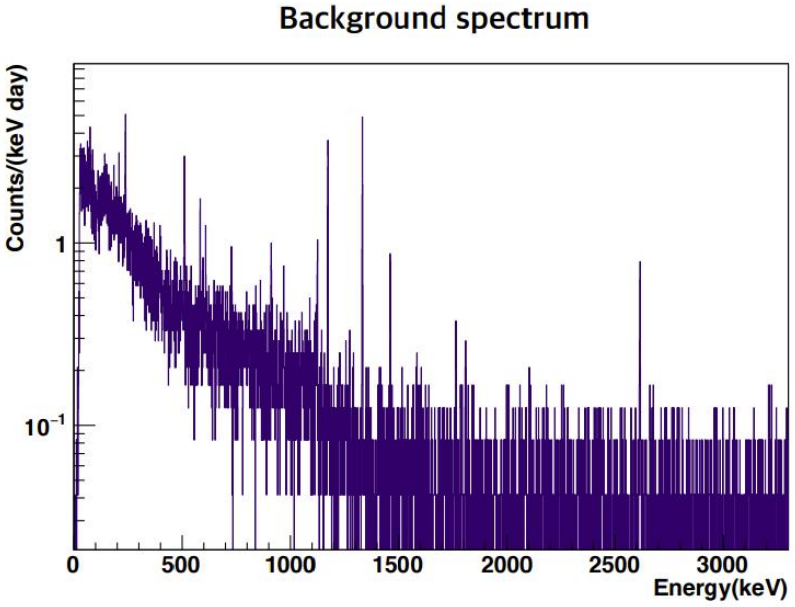
CC1



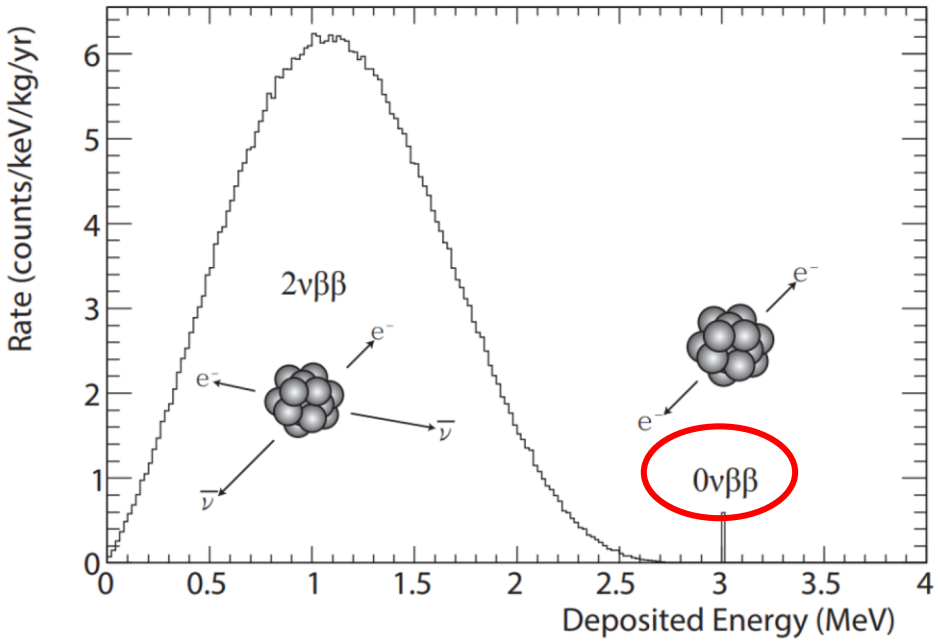


CC2





0νββ decay & Experiments

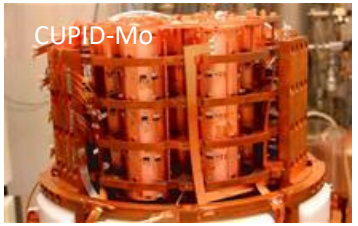


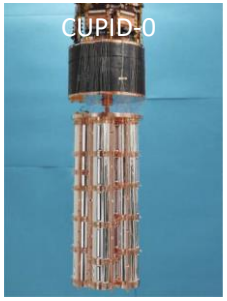
Candidates	$Q_{\beta\beta}$ (MeV)	N.A.(%)	Exp.
$^{48}Ca \rightarrow ^{48}Ti$	4.268	0.187	
$^{76}Ge \rightarrow ^{76}Se$	2.039	7.8	MAJORANA, GERDA/LEGEAND
$^{82}Se \rightarrow ^{82}Kr$	2.998	8.8	CUPID-0
$^{96}Zr \rightarrow ^{96}Mo$	3.356	2.8	
$^{100}Mo \rightarrow ^{100}Ru$	**3.034**	**9.7**	**AMoRE** CUPID-Mo, CUPID
$^{110}Pd \rightarrow ^{110}Cd$	2.017	11.7	
$^{116}Cd \rightarrow ^{116}Sn$	2.813	7.5	Aurora
$^{124}Sn \rightarrow ^{124}Te$	2.293	5.8	
$^{130}Te \rightarrow ^{130}Xe$	2.528	34.1	CUORE
$^{136}Xe \rightarrow ^{136}Ba$	2.458	8.9	EXO, nEXO, KamLAND-Zen
$^{150}Nd \rightarrow ^{150}Sm$	3.371	5.6	

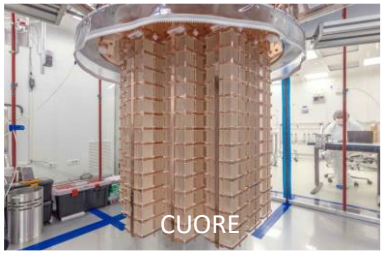
[candidates & Exps.]

0νββ decay

- Direct test of Majorana nature of neutrino
- Lepton number violation process
- Absolute neutrino mass







MoO3 based Crystal scintillators

	Inter. BG	LY at 10 K (%)	Density (g/cm^3)	Melt. Point (℃)	Hygroscopic
$CaMoO_4$	Higher (^{48}Ca)	100	4.2	~1450	No
Li_2MoO_4	Lower	5	3.0	~700	Strong
$PbMoO_4$	N.A. (^{210}Pb)	10	6.8	~1065	No
$Na_2Mo_2O_7$	Lower	140	3.7	~600	Weak