SuperK-Gd

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On behalf of

The Super-Kamiokande Collaboration

- physics benefits
- the EGADS demonstrator
- implementation in Super-Kamiokande

EPS-HEP 2017
2017/07/06, Lido, Venice

MARIE CURIE ACTIONS
H2020-MSCA-RISE-2014-GA641540, SKPLUS

Super-Kamiokande: superb physics thanks to **water-cherenkov technique**

- discovery of **ν** oscillations in the atmospheric sector
- key in the understanding of the solar-**ν** problem
- ....
- evidence for the appearance of atmospheric ν_τ
- first indication of terrestrial matter effects on solar-**ν**

most stringent limits on:

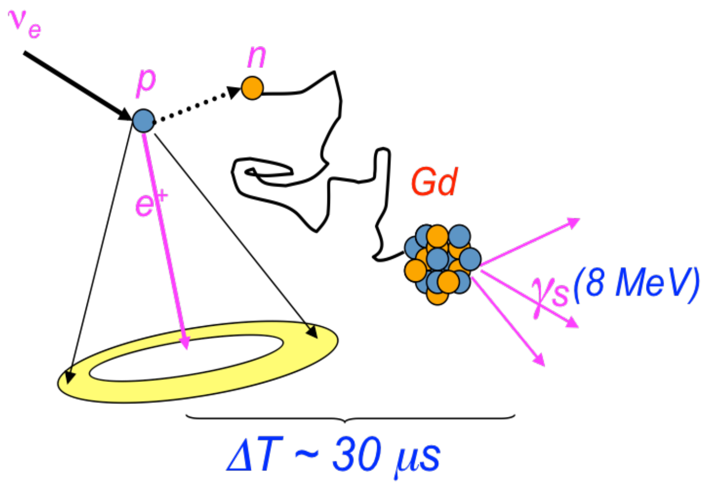
- nucleon decay
- WIMP-type **D**ark **M**atter from indirect search
- **D**iffuse **S**upernova **N**eutrino **B**ackground

Superk-Gd (GADZOOKS!): go further with **high efficiency neutron tagging**

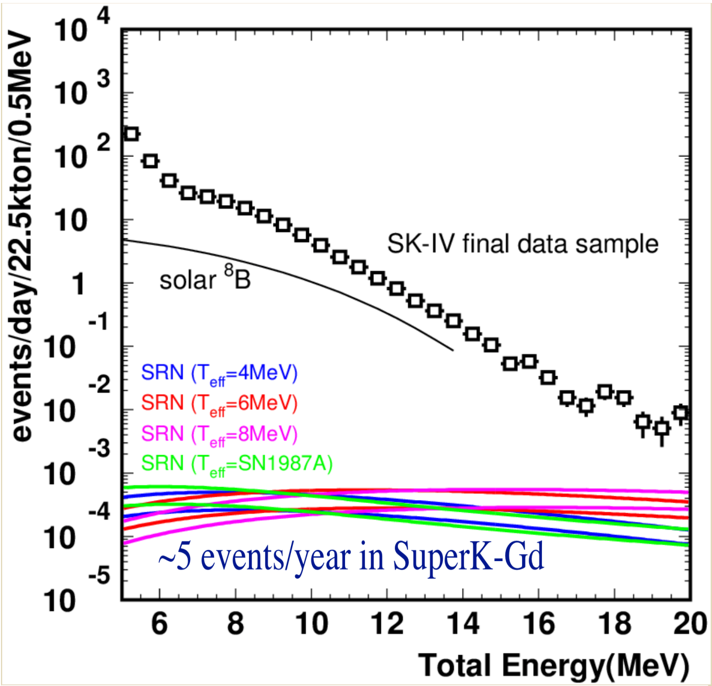
Beacom and Vagins PRL93,171101 (2004)

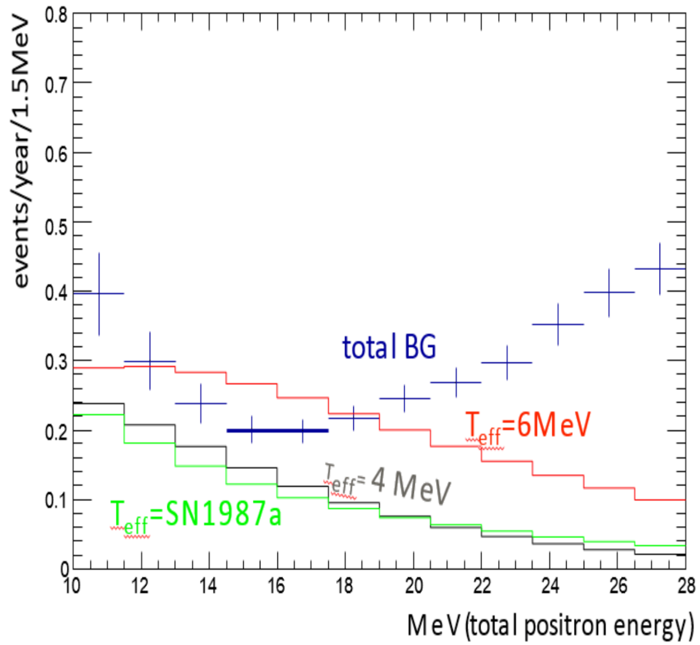
adding a 0.2 % by mass of a Gd compound, $Gd_2(SO_4)_3$, **to SK** water, the majority of final state **neutrons** produced in the interactions (90% captured × 90% reconstructed) will, after thermalized, be **captured by Gd** after ~30 μs and detected through the **8 MeV γ ray cascade** from its de-excitation

➔ anti-neutrino tagging at inverse β reaction



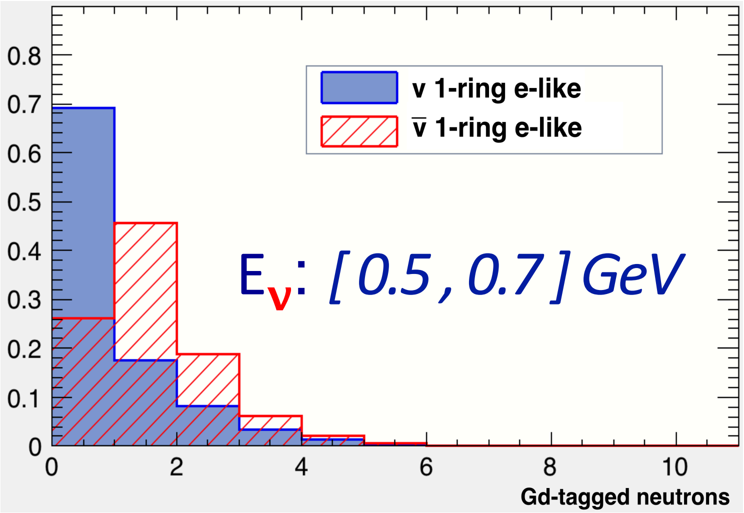
- be in position of discovering **DSNB** from the very much reduced background

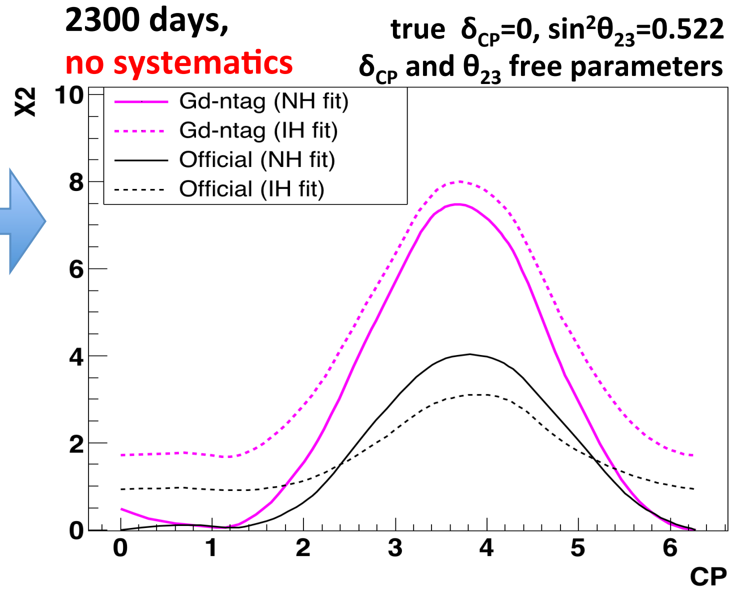




- improve pointing accuracy for Supernova
- Supernova early warning from Si burning **ν**s
- high precision solar- **ν**s elements from reactor **ν**s (if available)

➔ neutrino / anti-neutrino discrimination by neutron counting

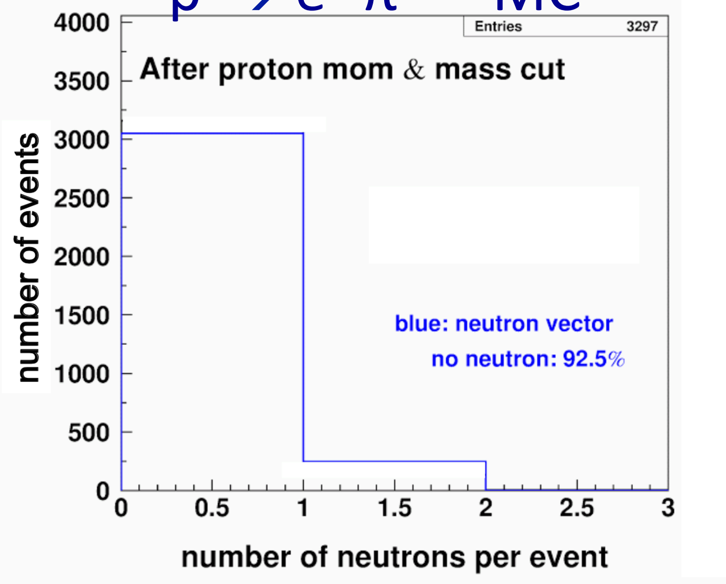




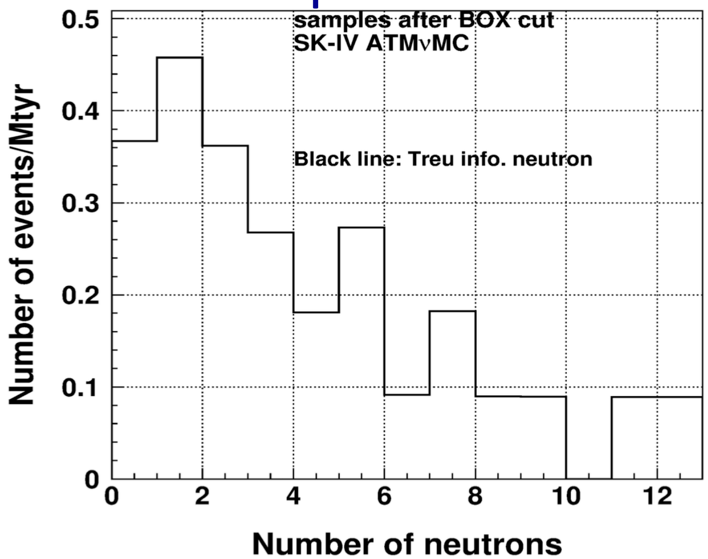
very significant increase in fraction of δ_{CP} over 90% CL

➔ neutron veto

p → $e^+ \pi^0$ MC



Atmospheric ν MC



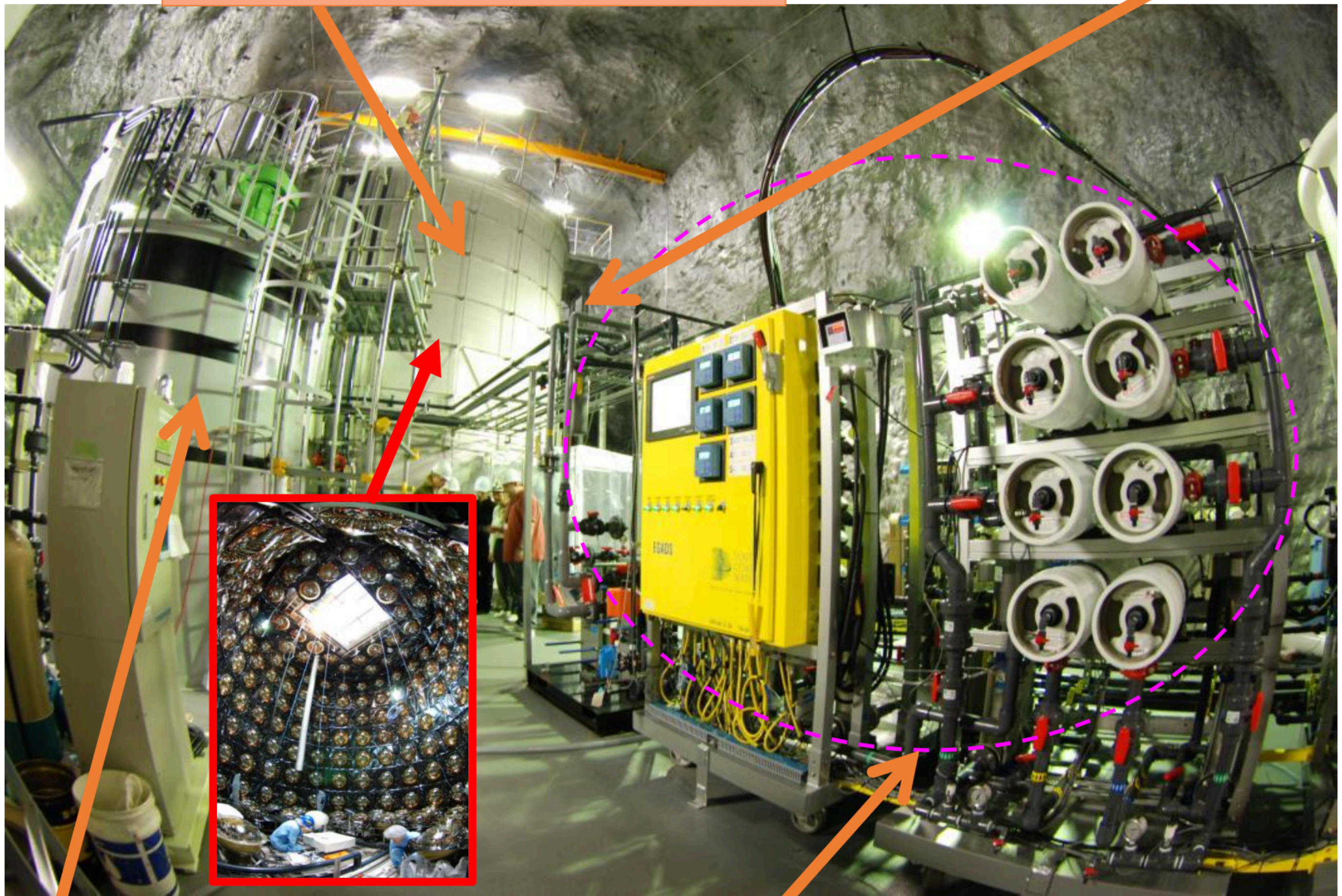
background probability reduced from 44% to 9%

➔ and more ....

EGADS @ hall near the SK area

Evaluating Gadolinium's Action on Detector Systems

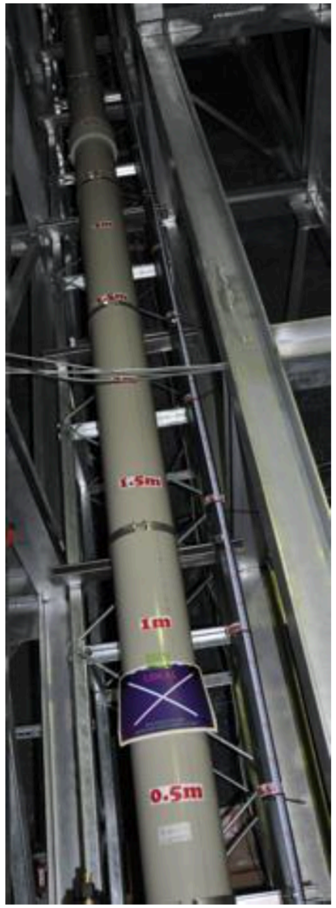
200 m[3] tank with 240 PMTs



15m[3] tank to dissolve Gd

Gd water circulation system
(purify water with Gd)

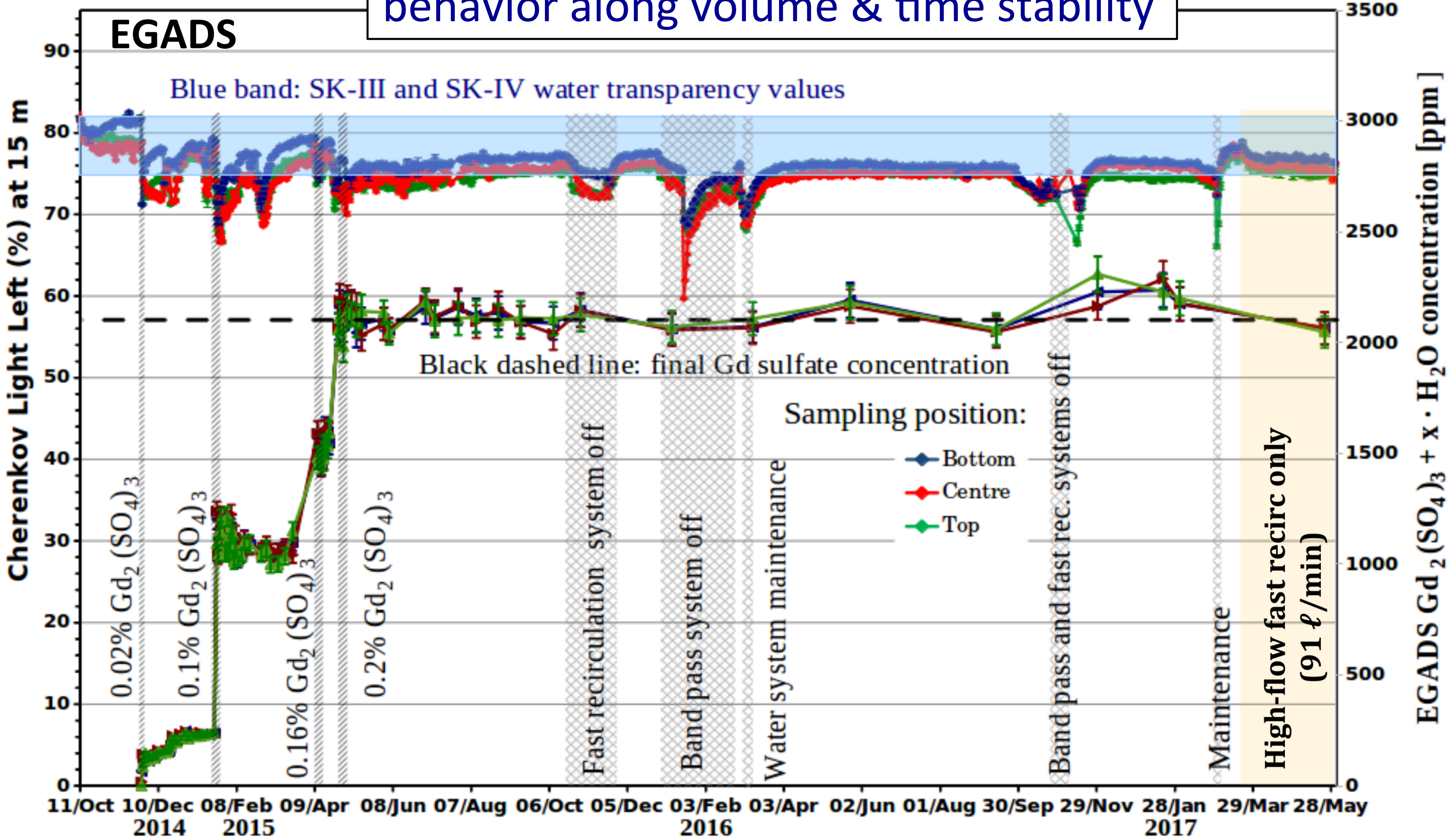
Transparency measurement
(UDEAL)



water transparency *by UDEAL*

$Gd_2(SO_4)_3$ concentration *by AAS*

behavior along volume & time stability

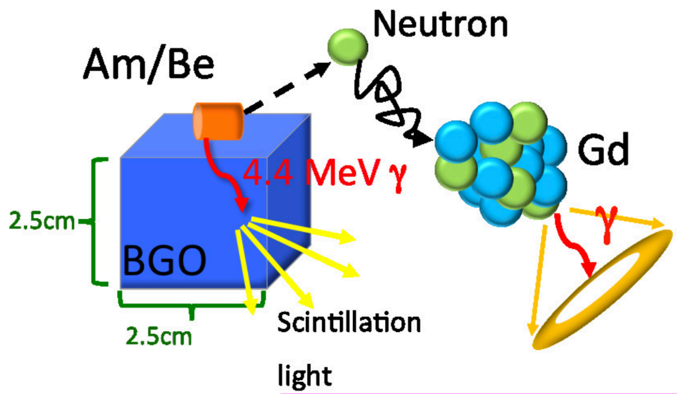


→ Gd-loaded water transparency within the SK ultrapure range

→ lossless (>99.99%) Gd-capable water system [> 500 turnovers so far]

Some **calibration results**:

mimicking inverse **β** decay signals with an Am/Be source and BGO scintillator



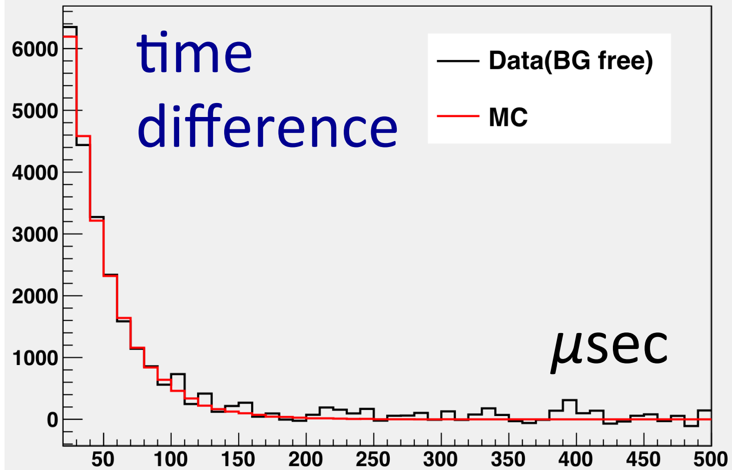
$$^{241}Am \longrightarrow {}^{237}Np + \alpha$$

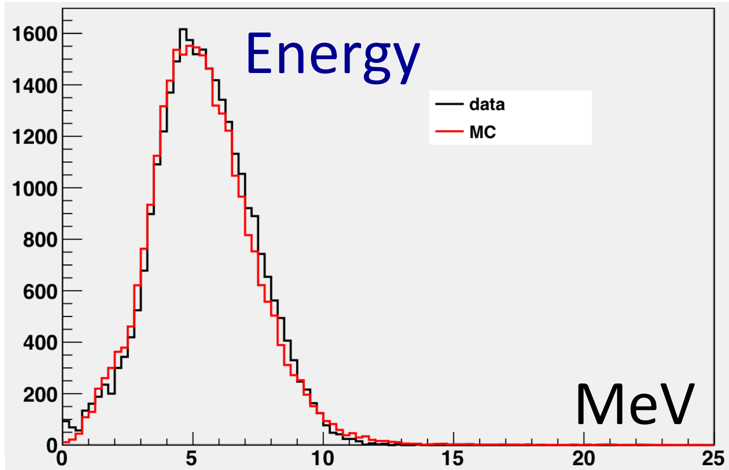
$$\alpha + {}^{9}Be \longrightarrow {}^{12}C^{*} + n, {}^{12}C + n$$

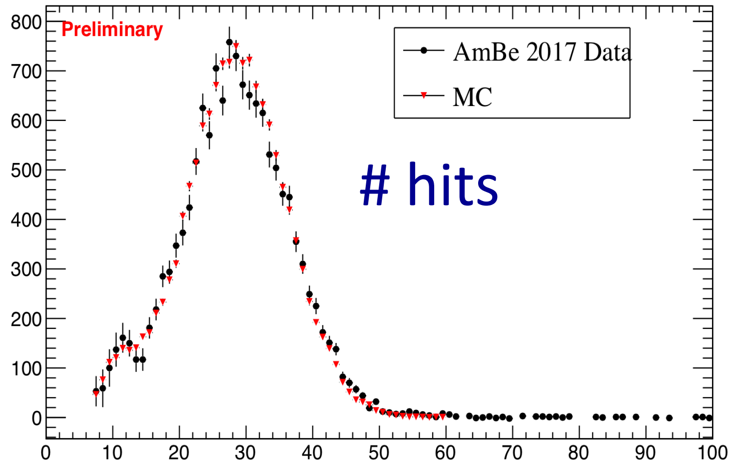
$$^{12}C^{*} \longrightarrow {}^{12}C + \gamma(4.43MeV)$$

	Gadolinium Sulfate Octahydrate Concentration		
	2178 ± 76 ppm	1055 ± 37 ppm	225 ± 8 ppm
Data	29.89 ± 0.33	51.48 ± 0.52	130.1 ± 1.7
MC	30.03 ± 0.77	53.45 ± 1.19	126.2 ± 2.0

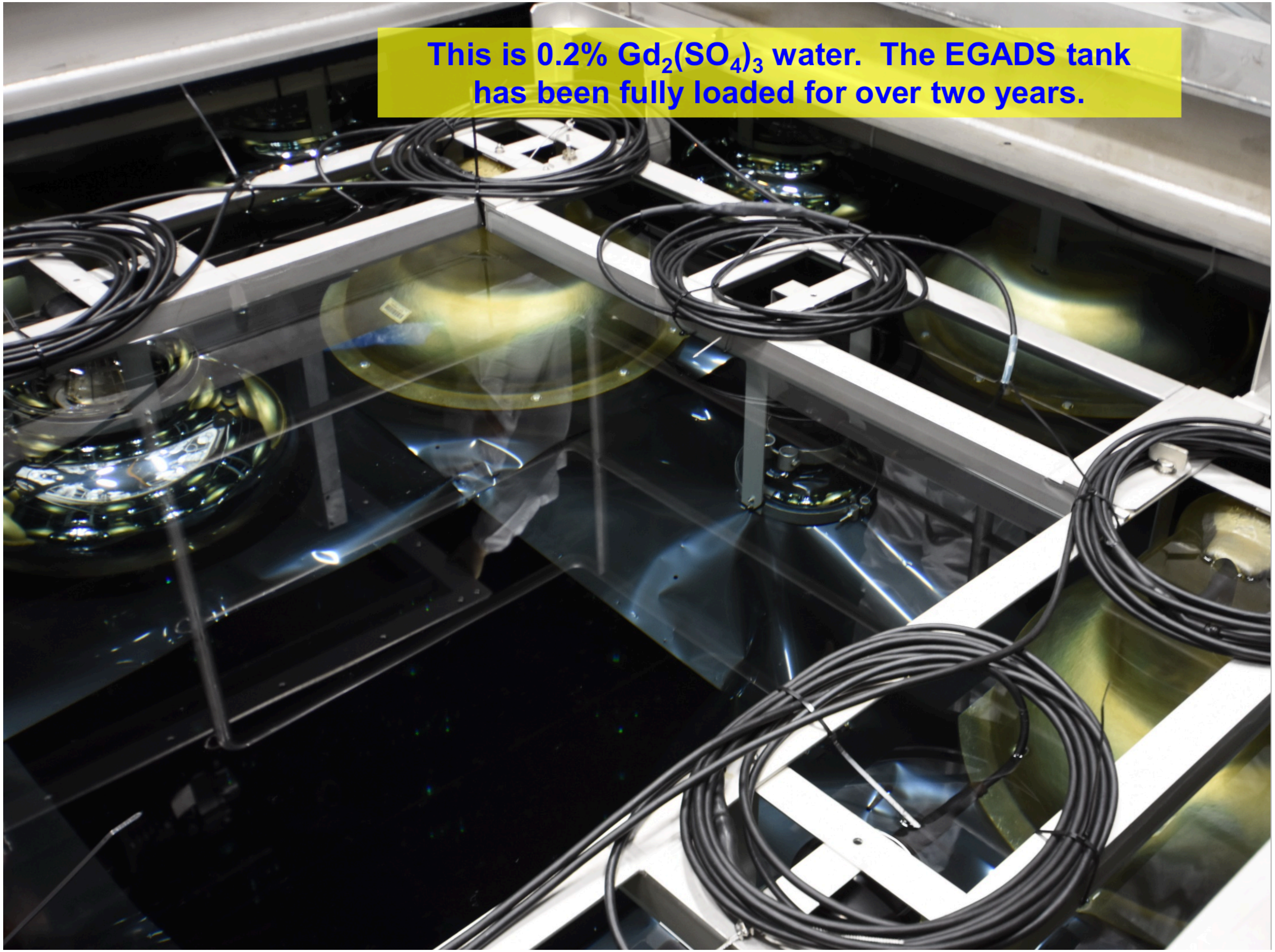
mean capture time of neutron (μsec)







wonderful cleanness and shininess all around after more than two years



Radioactivity Contamination at $Gd_2(SO_4)_3$ very seriously assessed [source of severe background signals all along the Fiducial Volume]

Typical activities of salts in the market:
(from over 10 samples from 5 providers)

Physics based requirements for radioactive contaminations

Radioactive chain	Part of the chain	mBq/kg	SRN (mBq/kg)	Solar ν (mBq/kg)
^{238}U	^{238}U	50	< 5	-
	^{226}Ra	5	-	< 0.5
^{232}Th	^{228}Ra	10	-	< 0.05
	^{228}Th	100	-	< 0.05
^{235}U	^{235}U	32	-	< 3
	^{227}Ac / ^{227}Th	300	-	< 3

work done mostly at the
Canfranc Underground Laboratory

- salts from different providers had in general similar contaminations
- Superk-Gd can not afford those amounts of RI, **approaches to reduce** them
  - ✓ by ourselves from received batches [a lot of work being done in Kamioka, not discussed here]
  - ✓ Cooperative development of pure salts with chemical Co.

we are cooperating with the following companies:

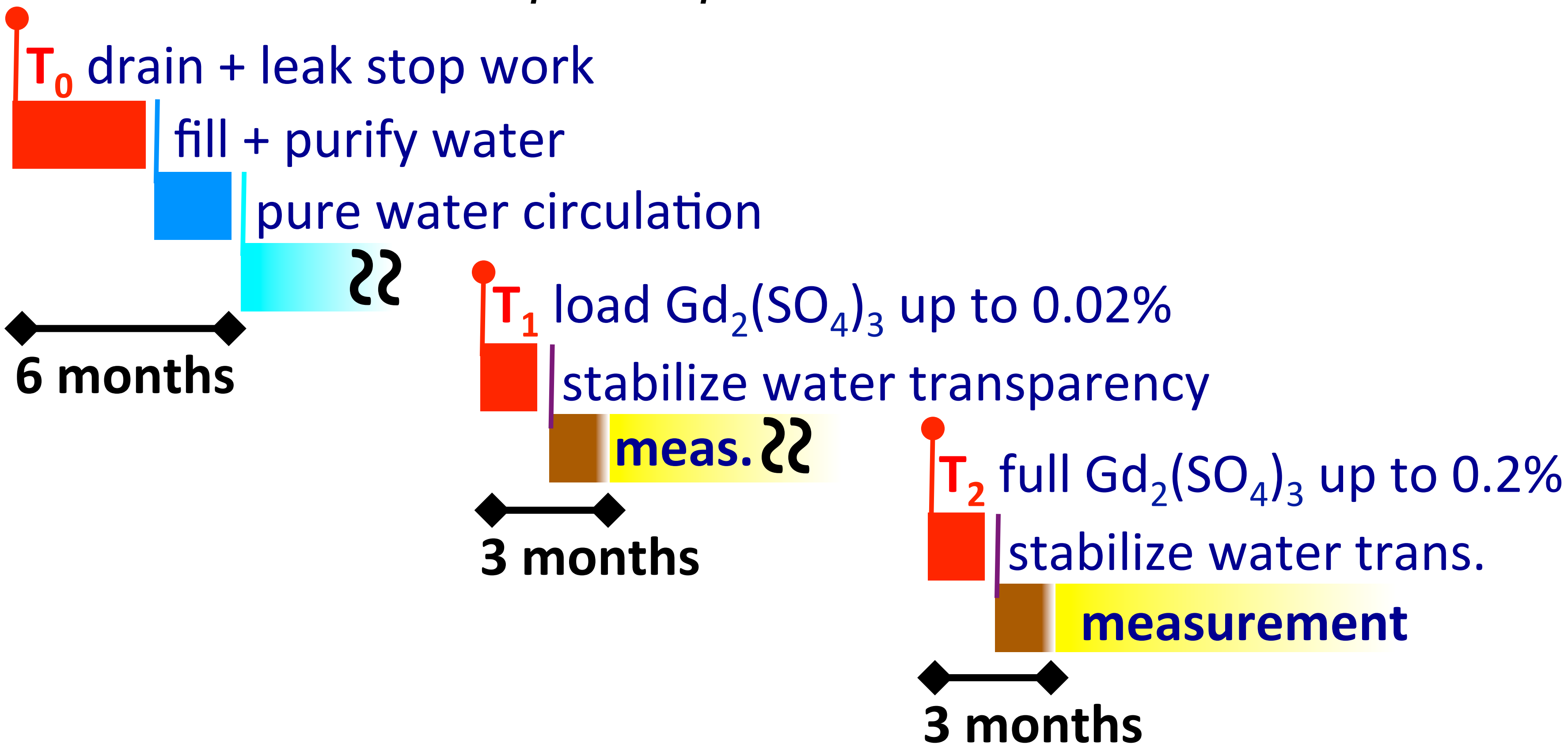
Molycorp, *Shin-Etsu Chemical Co. Ltd.*, *Kanto Chemical Co. Inc.*, *Wako Pure Chemical Ind. Ltd.*, and *Nippon Yttrium Co. Ltd.*

In the good track: reductions of *x*20 – *x*50 already achieved

Chain	main subchain isotope	**GSF**-1703-**C9**-702142	ICPMS meas.	**GSF-**1604-**C7**-160303	ICPMS meas.	**GSF-**1611 **C8**-003	**GSF**-1703 **C8**-(RGD-OSF-005)	ICPMS meas.	
^{238}U	**^{238}U**	**< 13**	**0.7**	**< 20**	**0.2**	**< 13**	**< 9,2**	**0.1**	✔
	^{226}Ra	**0.7 ± 0.4**		**< 0.64**		**< 0.3**	**< 0.26**		✔
^{232}Th	**^{228}Ra**	**< 0.39**	^{232}Th **1.3**	**< 0.67**	^{232}Th **0.2**	**< 0.3**	**< 0.26**	^{232}Th **0.2**	*x*5
	^{228}Th	**1.7 ± 0.4**		**0.5 ± 0.2**		**< 0.4**	**< 0.37**		*x*7
^{235}U	**^{235}U**	**< 1.3**		**< 0.7**		**< 0.6**	**< 0.51**		✔
	^{227}Ac/^{227}Th	**< 3.1**		**< 2.3**		**< 1.9**	**< 1.7**		✔

Intensive work at
- Canfranc Underground Laboratory
- Kamioka Observatory
- Boulby Underground Observatory (recently joined)
- probably LNGS also joints

SuperK-Gd time line → *3-phase procedure:*



decision about when to trigger it (T_0) taken jointly by T2K and SK:

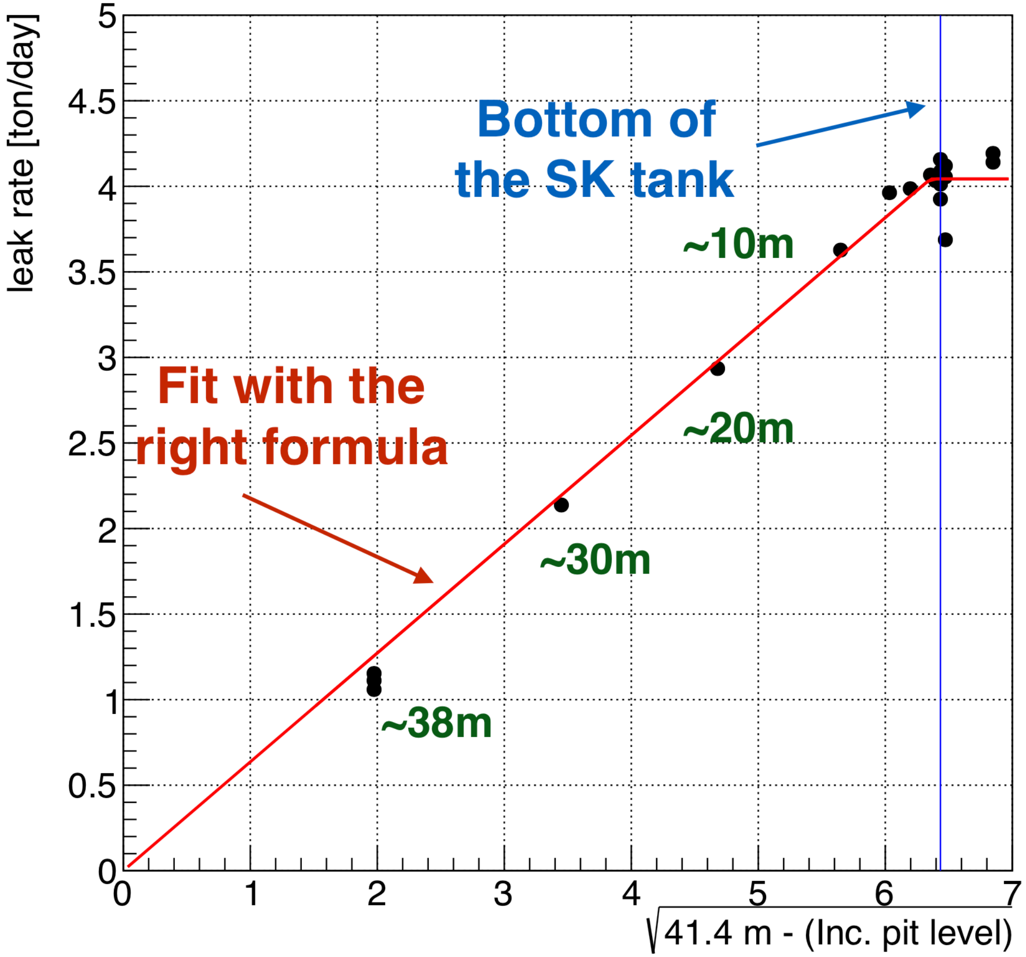
→ proposed to start refurbishment **by middle 2018**

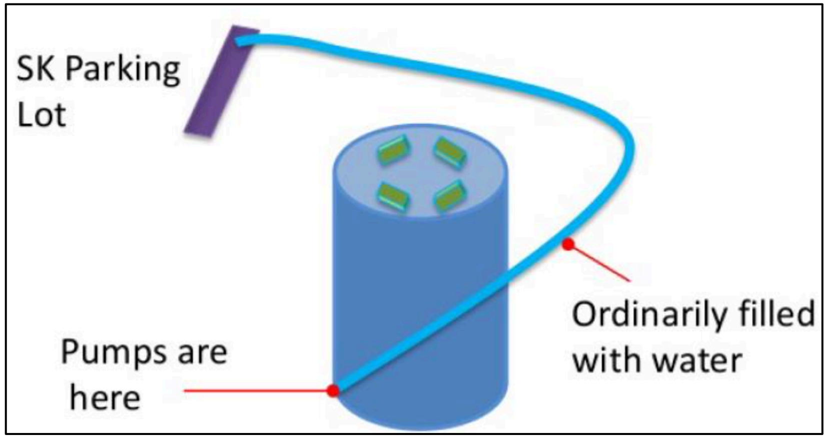
→ final decision will be made at J-PARC PAC meeting (July 24-26)

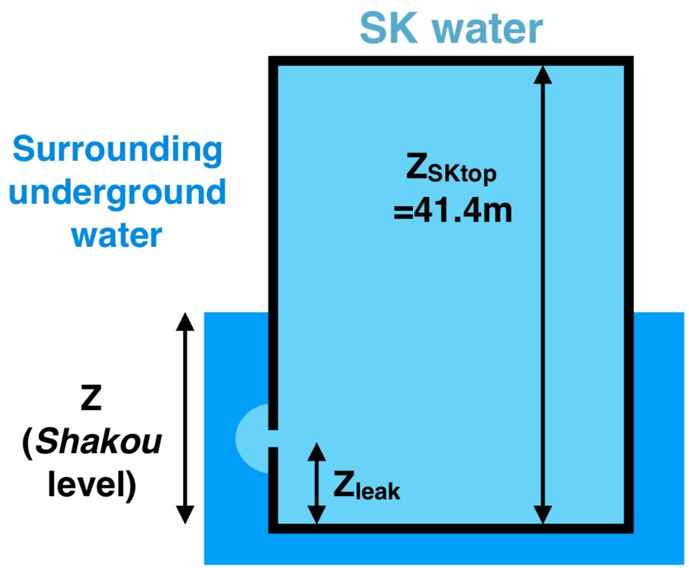
Further key items:

- refurbishment / leak stop
- the new water system

Estimating the location of the leak





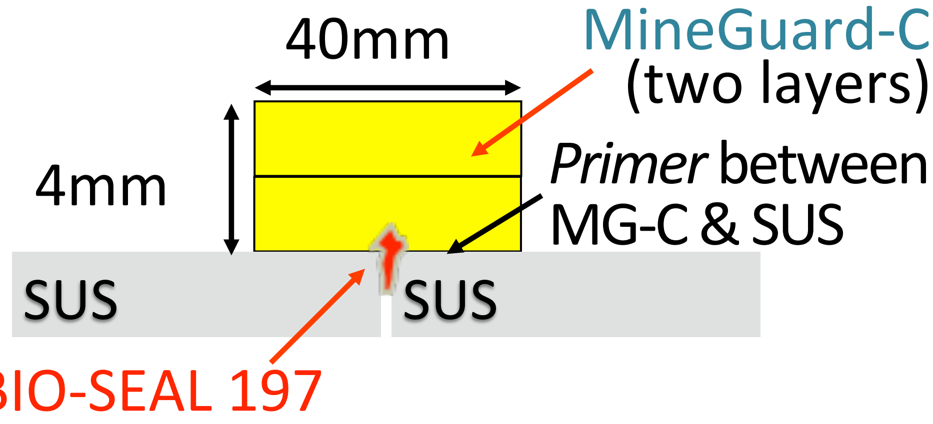


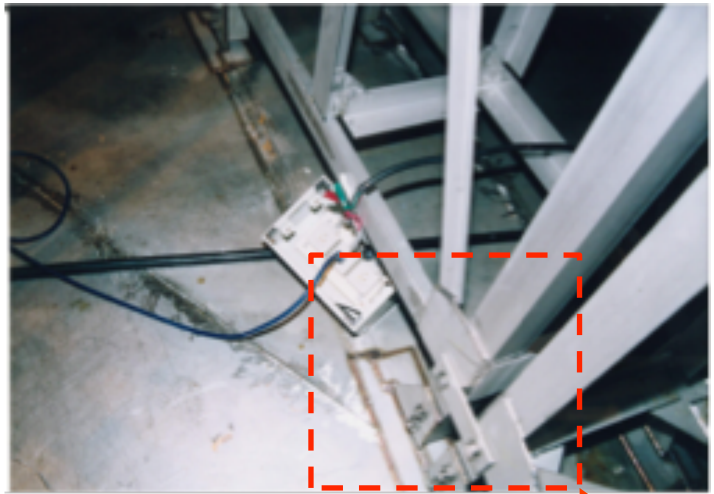
$$\Phi_{leak}(z) = \begin{cases} a \times \sqrt{z_{SKtop} - z} & (z > z_{leak}) \\ a \times \sqrt{z_{SKtop} - z_{leak}} & (z < z_{leak}) \end{cases}$$

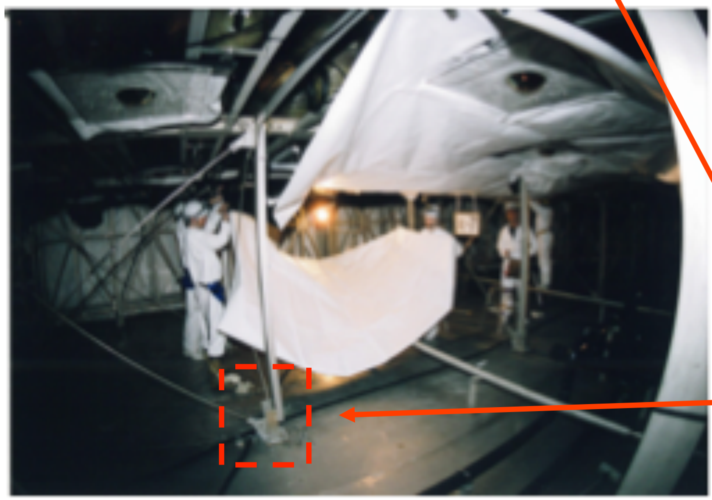
a: Constant proportional to the hole size

➔the data indicate that it is near the bottom of the SK detector

- double coating with
  1. BIO-SEAL 197 epoxy resin: sneaks into small gaps
  2. Mine Guard C viscous material: allows more displacement (less penetration though)



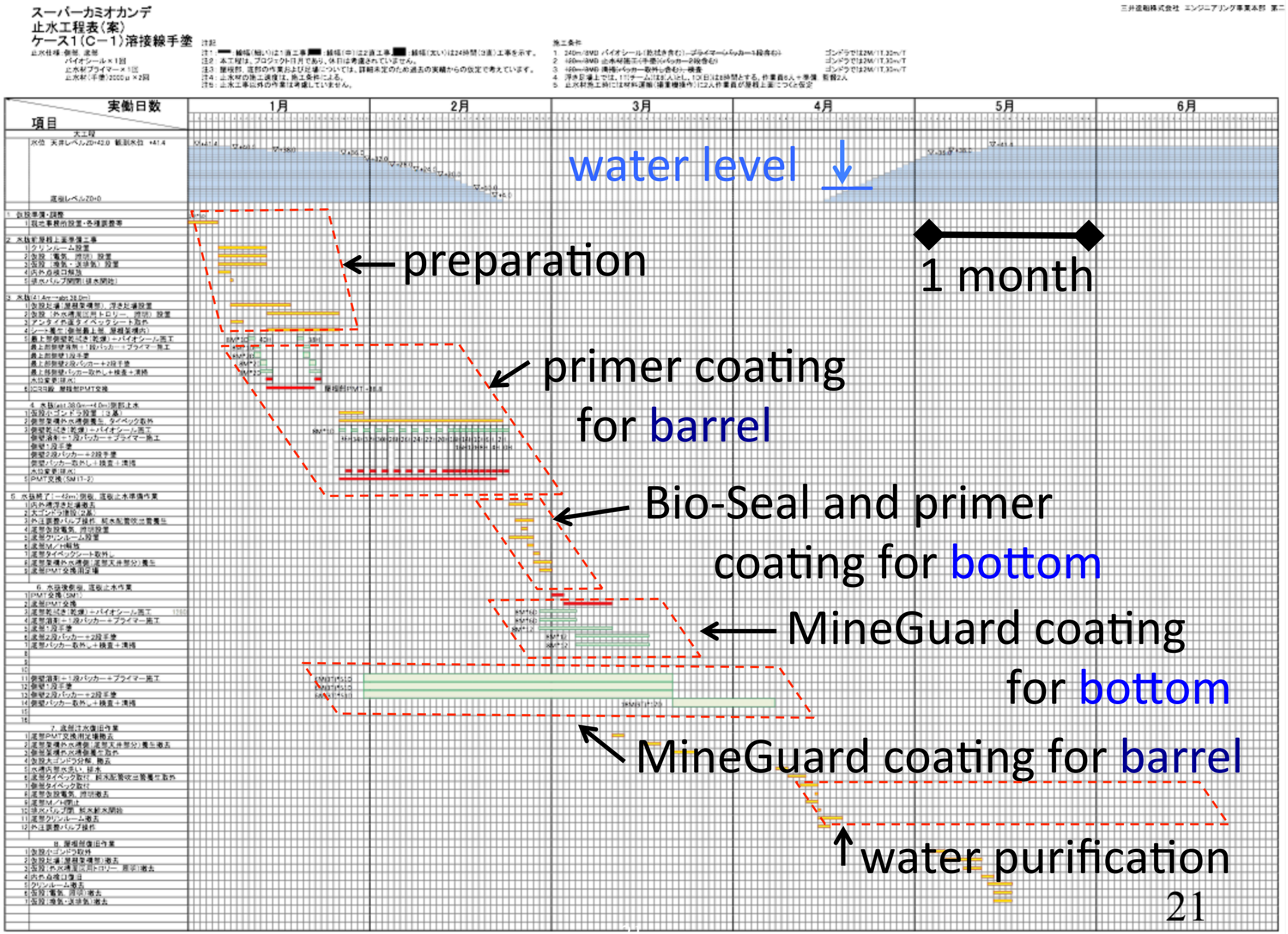




particularly suspicious:
barrel PMT frame anchor at bottom

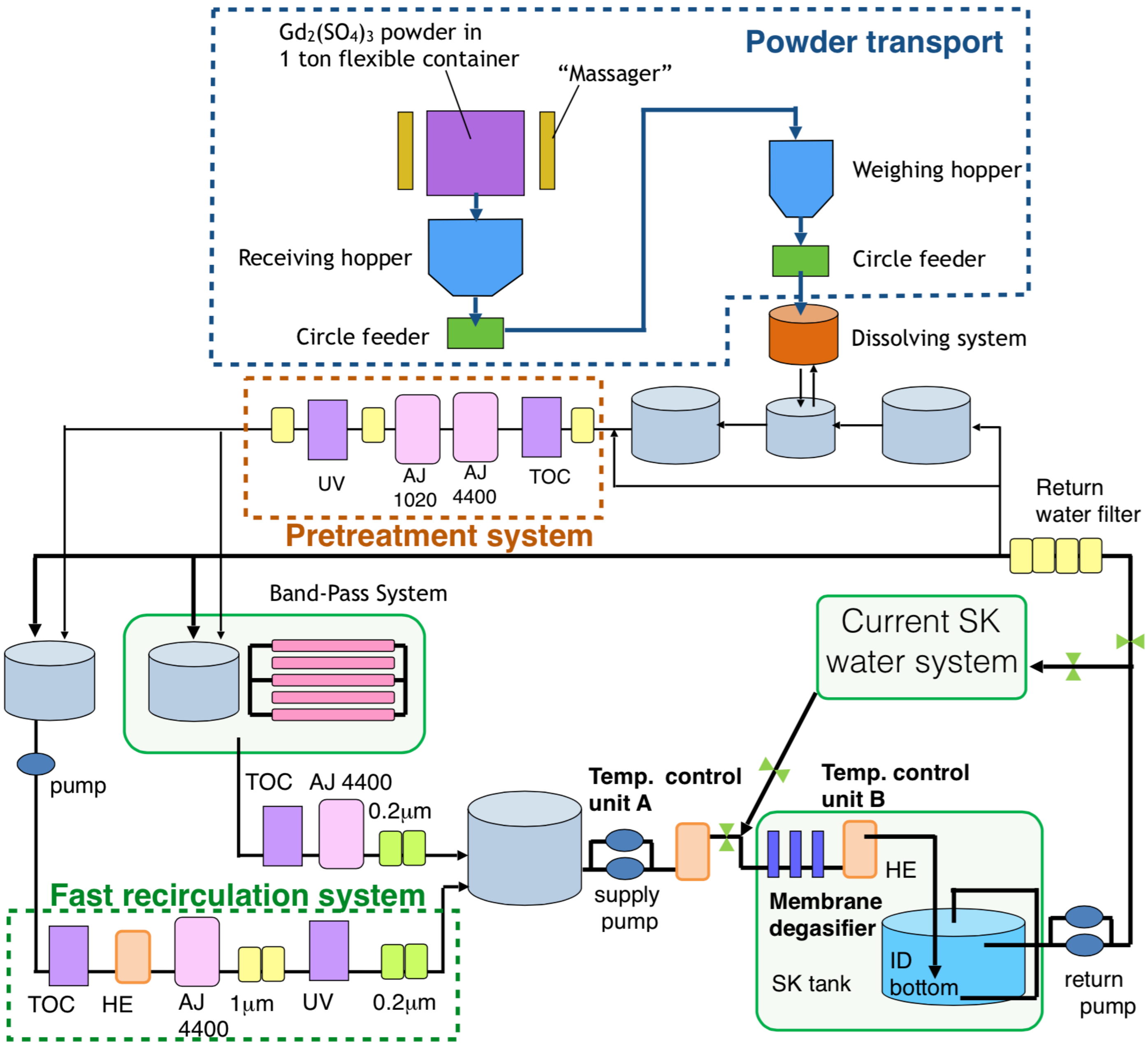
fixing the leak at SK tank

detailed, day-to-day schedule prepared by *Mitsui & Co. Ltd*:

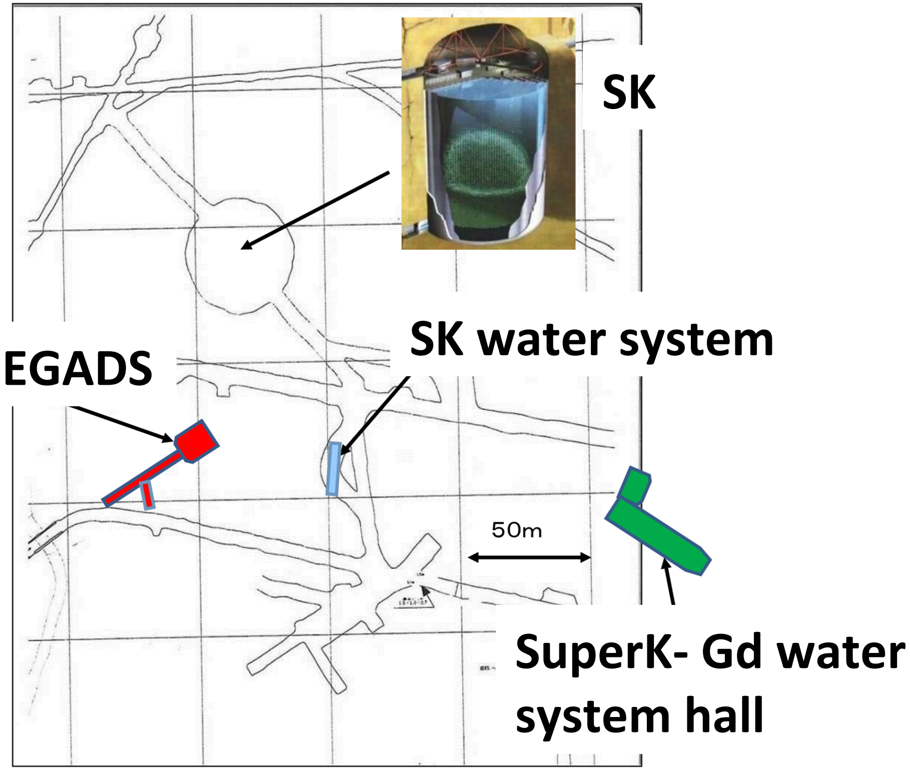


In total: ~ 6 months needed for the job

SuperK-Gd water System   60 m³/hr selective filtration system



Scale-up of the EGADS system with sophisticated powder transport and dissolving systems


SK
SK water system
EGADS
50m
SuperK- Gd water
system hall


SuperK-Gd water system
being built in Hall G (4K m^3)

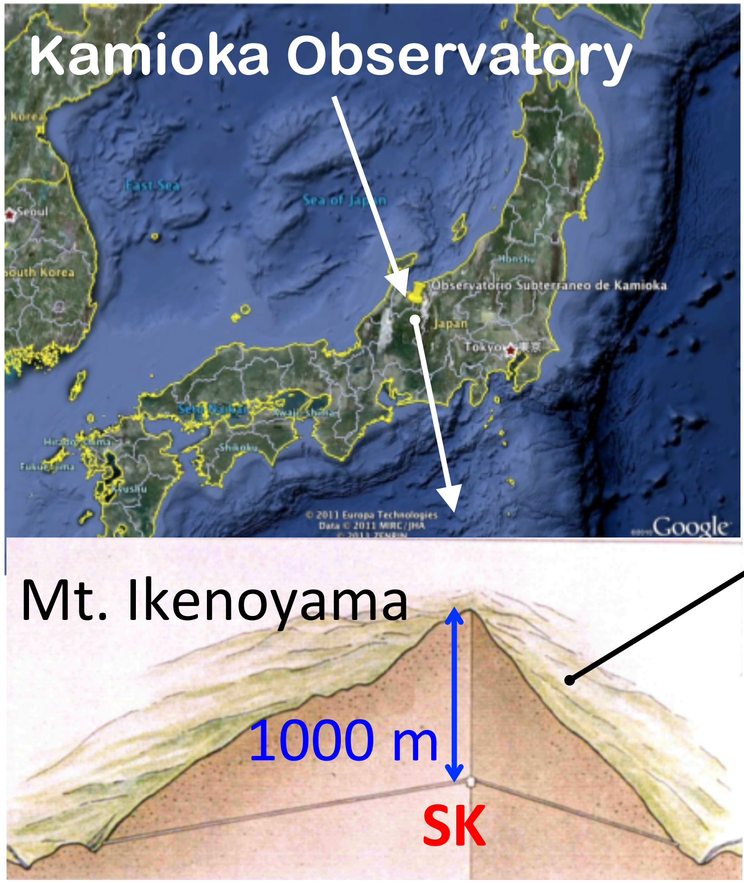
Summary / Conclusions / Outlook

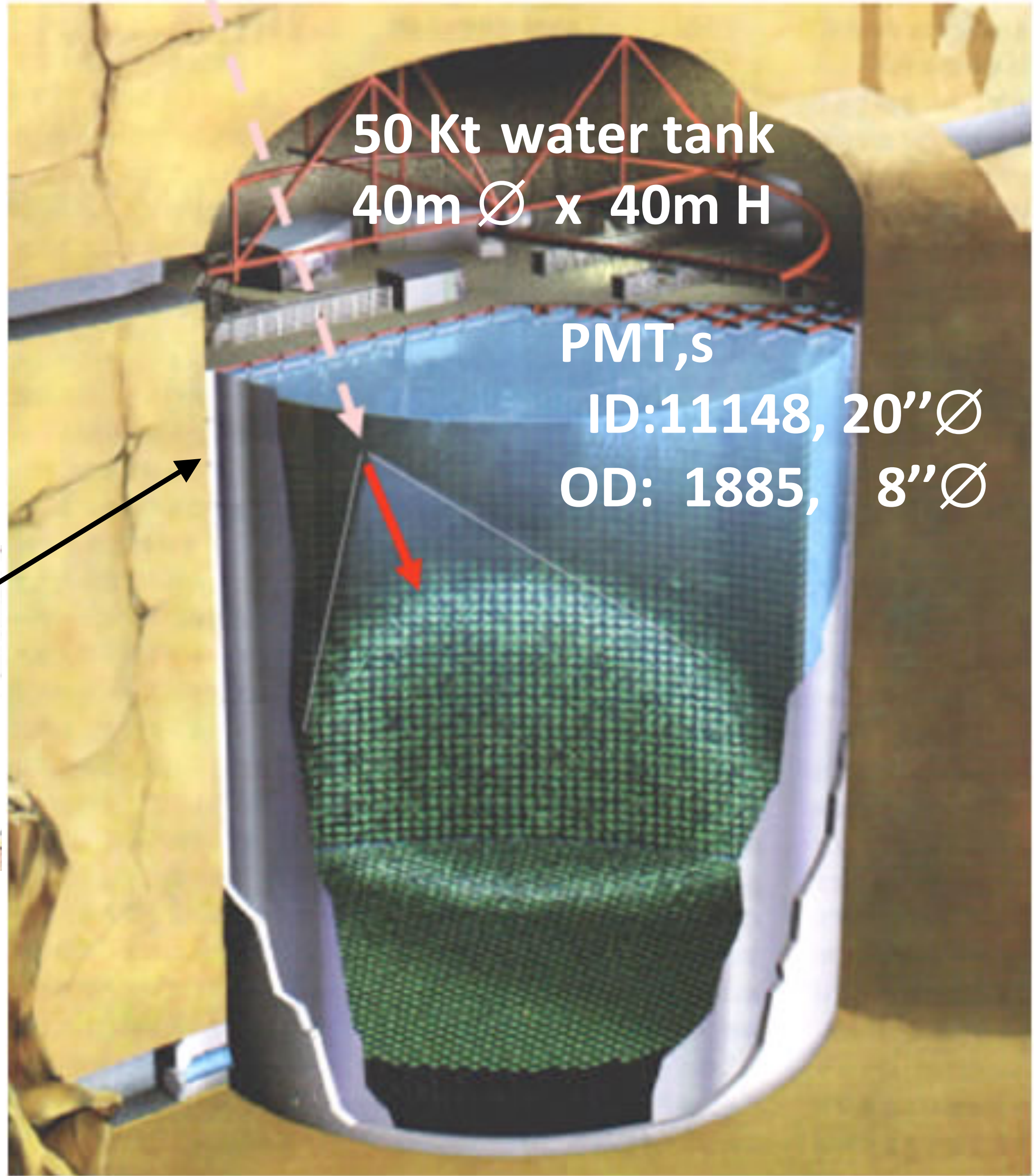
- Superk-Gd enlarges significantly the window of SK's physics measurements

- EGADS has demonstrated its viability and reliability

- The implementation of SuperK-Gd will most probably begin in 2018 additional

The *Super-Kamiokande* experiment at Kamioka Observatory



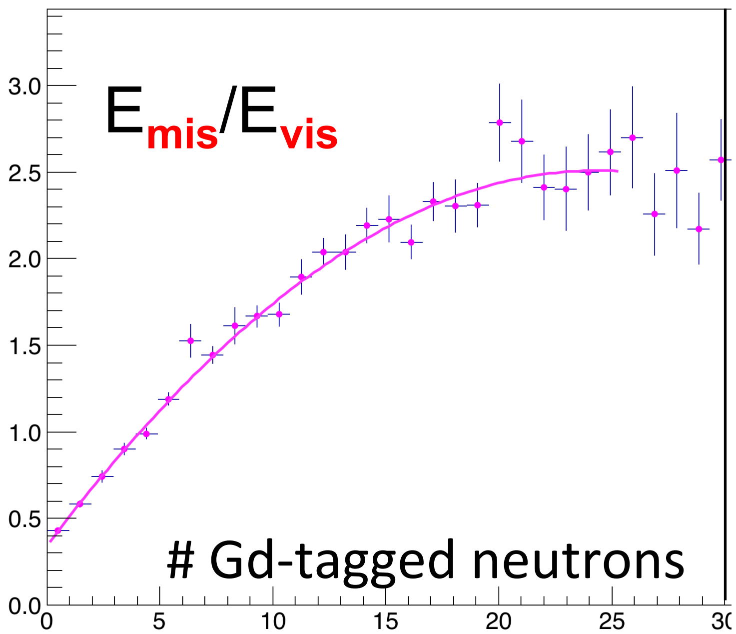


SK **measures** *Cherenkov radiation*

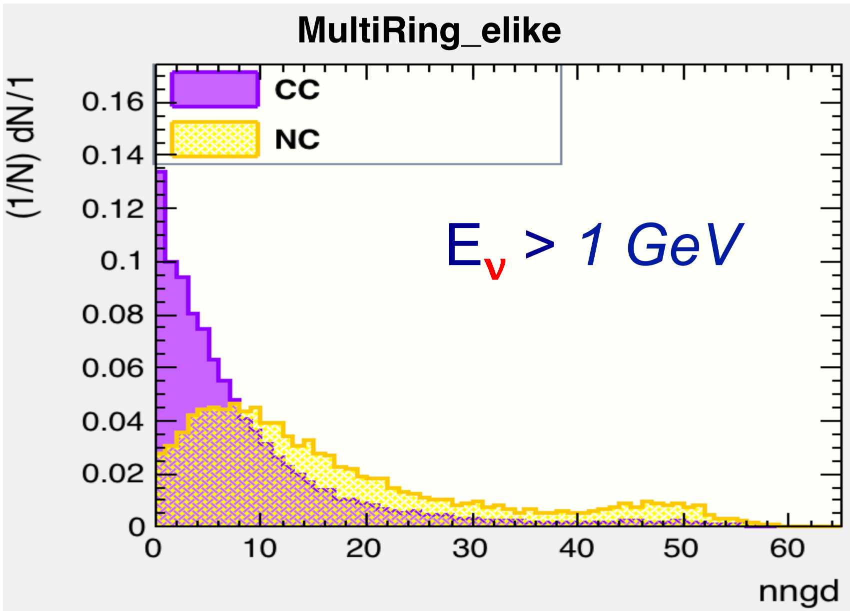
DSNB events number with 10 years observation

model	10-16MeV (evts/10yrs)	16-28MeV (evts/10yrs)	Total (10-28MeV)	significance (2 energy bin)
T_{eff} 8MeV	11.3	19.9	31.2	5.3 σ
T_{eff} 6MeV	11.3	13.5	24.8	4.3 σ
T_{eff} 4MeV	7.7	4.8	12.5	2.5 σ
T_{eff} SN1987a	5.1	6.8	11.9	2.1 σ
BG	10	24	34	----

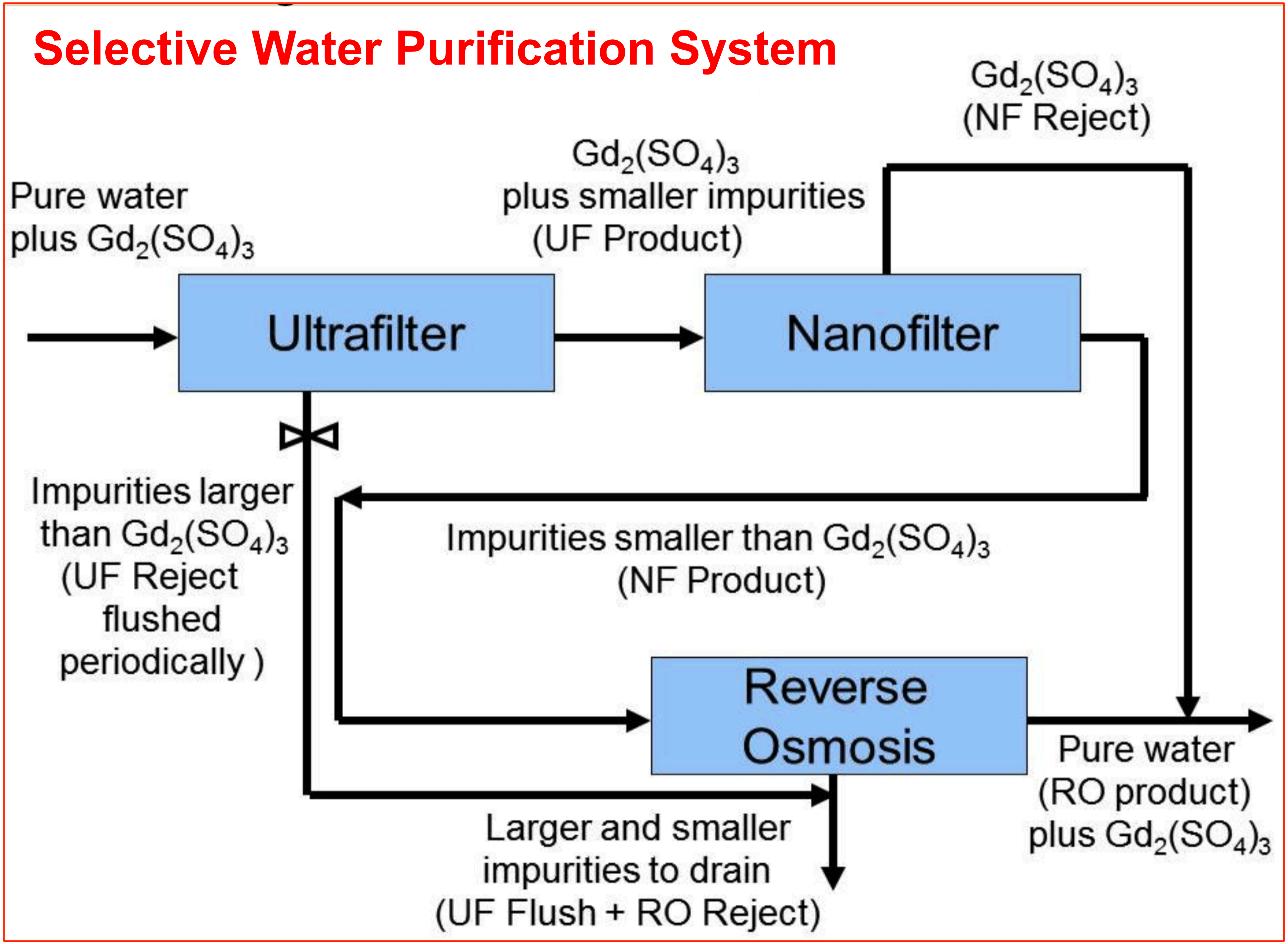
→ Improvement of E_ν reconstruction with tagged neutrons



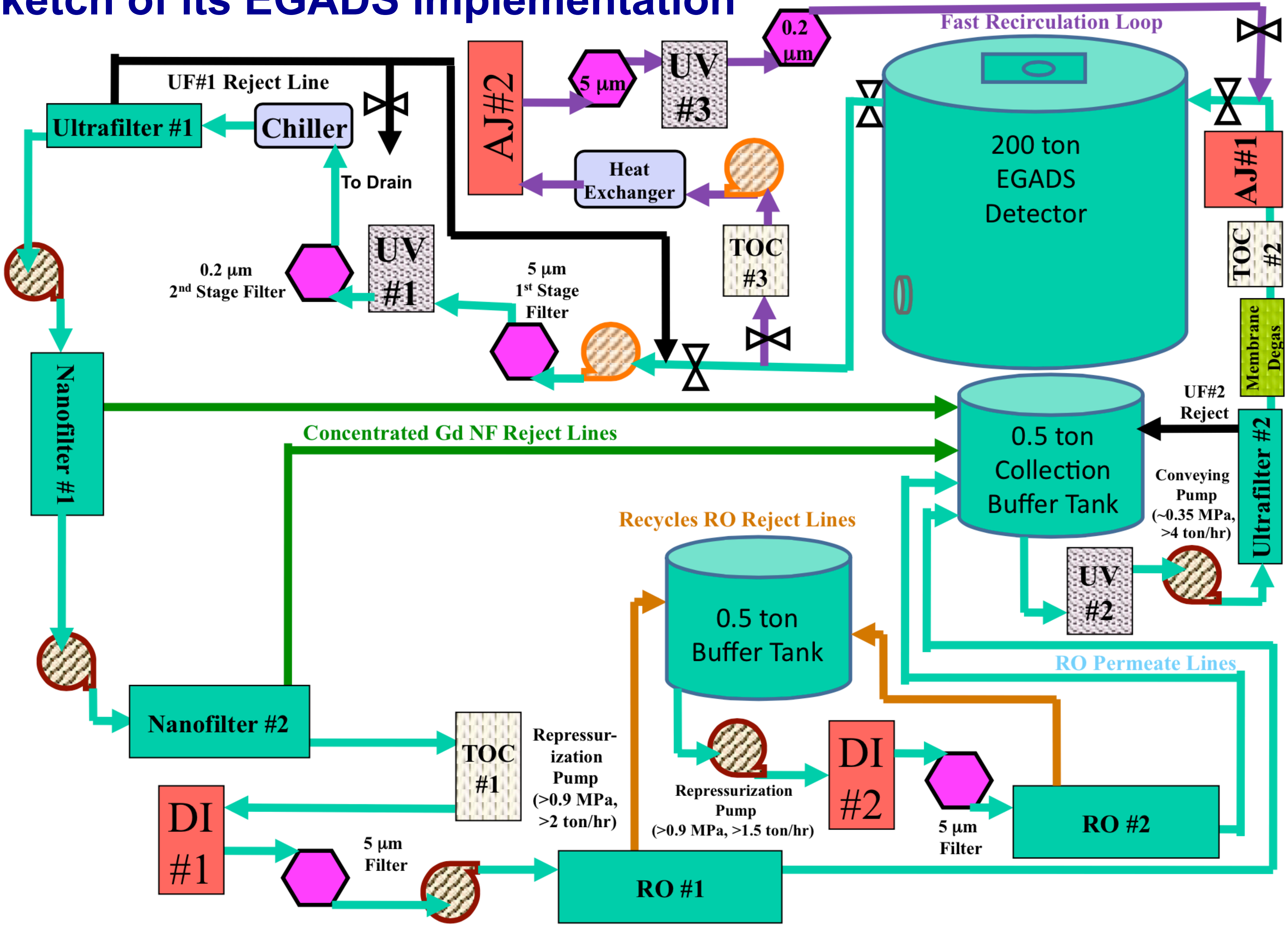
→ NC / CC discrimination by n-tagging



The key to Superk-Gd:



Selective Water Purification System: sketch of its EGADS implementation



water transparency measurement

UDEAL measures absolute attenuation lengths at 7 wave-lengths:
in **nm** (its contribution to Cherenkov light is indicated in brackets)

337 (0.25), **375** (0.25), **405** (0.21), **445** (0.14), **473** (0.11), **532** (0.04), **595** (.003)

		Measured radioactivity in mBq/kg for the $Gd_2(SO_4)_3$ batches purchased to date								
Chain	**Sub-chain**	**Standford Materials** 09/04	**Standford Materials** 10/08	**Beijing Jinghonganxin** 12/08	**Changshu Huanyu** 13/02	**Beijing Jinghonganxin** 13/03	**Standford Materials** 13/08	**HK Tai Kun** 13/07a	**HK Tai Kun** 13/07b	**Standford Materials** 14/12
^{238}**U**	^{238}**U**	51 ± 21	< 33	292 ± 6	74 ± 28	242 ± 6	71 ± 20	47 ± 26	73 ± 27 June 2015	< 76
	^{226}**Ra**	8 ± 1	2.8 ± 0.6	74 ± 2	13 ± 1	13 ± 2	8 ± 1	5 ± 1	6 ± 1	< 1.4
^{232}**Th**	^{228}**Ra**	11 ± 2	270 ± 16	1099 ± 12	205 ± 6	21 ± 3	6 ± 1	14 ± 2	3 ± 1	2 ± 1
	^{228}**Th**	28 ± 3	86 ± 5	504 ± 6	127 ± 3	374 ± 6	159 ± 3	13 ± 1	411 ± 5	29 ± 2
^{235}**U**	^{235}**U**	< 32	< 32	< 112	< 25	< 25	< 32	< 12	< 30	< 1.8
	^{227}**Ac**	214 ± 10	1700 ± 20	2956 ± 30	1423 ± 21	175 ± 42	295 ± 10	< 6	< 18	190 ± 6
Others	^{40}**K**	29 ± 5	12 ± 3	101 ± 10	60 ± 7	18 ± 8	3 ± 2	3 ± 2	8 ± 4	< 5
	^{138}**La**	8 ± 1	$<$	683 ± 15	3 ± 1	42 ± 3	5 ± 1	< 1	< 2	23 ± 1
	^{176}**Lu**	80 ± 8	21 ± 2	566 ± 6	12 ± 1	8 ± 2	30 ± 1	1.6 ± 0.3	< 2	2.5 ± 0.6

For DSNB

Expected signal ~5 events/year/FV

- ^{238}U Spontaneous Fission:

  ~ 5.5 [γ($E\gamma$>10.5 MeV) + 1n] / year / FV **x10 reduction desirable**

For solar neutrino

Current BG ~200 events/day/FV

- U (n) ~320events/day/ FV **x10 reduction desirable**
- Th/Ra (β,γ)~3 x 10 ^{5} events/day/ FV **x10^3 reduction needed**

Procedure

- **Barrel**
  - If the origin of the leak is at the place, the strain deformation is the reason of the leak.
  - Bio-seal will break if the strain deformation happens.
  - → Do only the MineGuard-C (reduce the total working time)
- **Bottom**
  - Defect of welding might be the reason. If the distortion is expected to be less than 0.01mm, painting Bio-Seal will work.
  - → Do Bio-Seal and cover the MineGuard-C