DSNB: Experimental Challenges

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SNOBS 2017 October 13, 2017

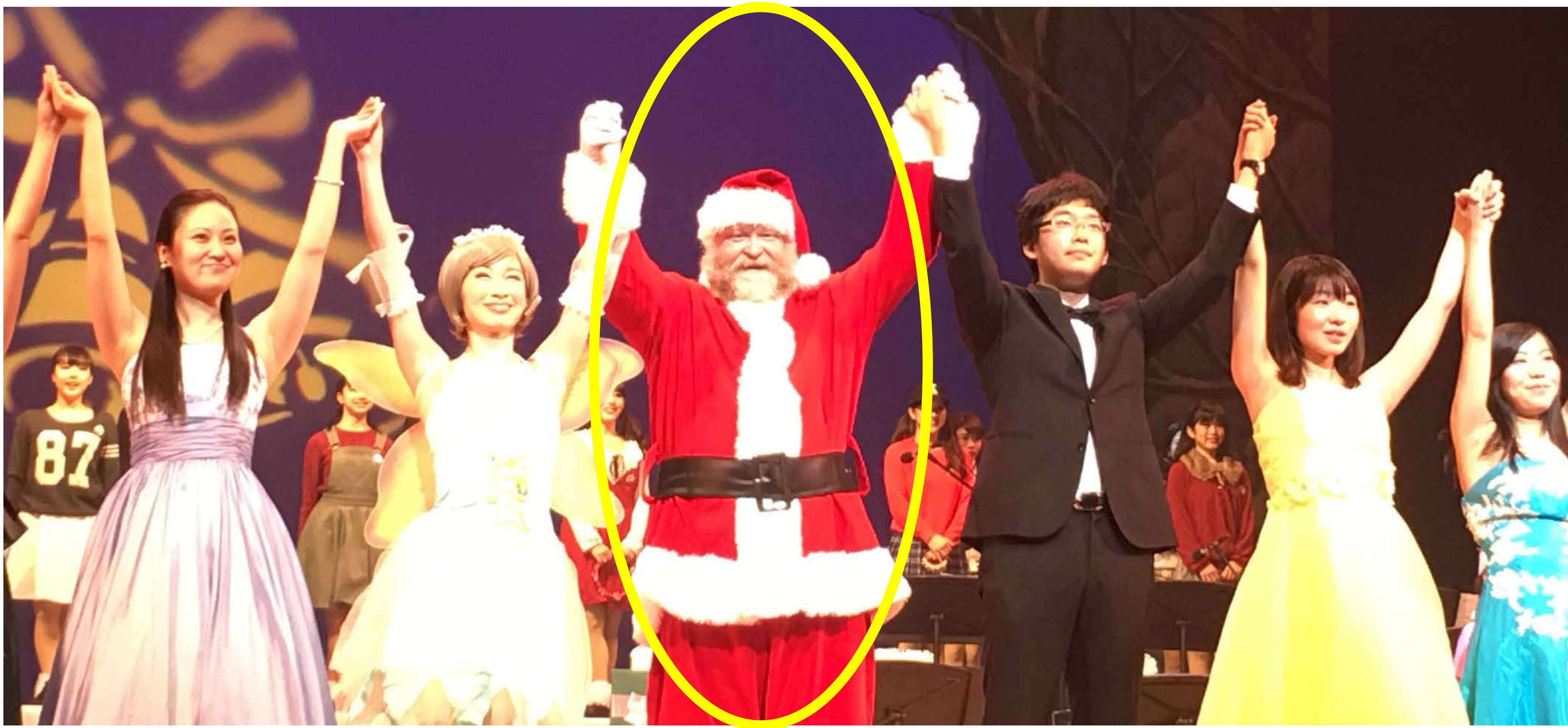
I saw this sign in Tokyo's Haneda Airport.


Santa
is
You!
Haneda Christmas Airport

Oh, my…
apparently
it's true:

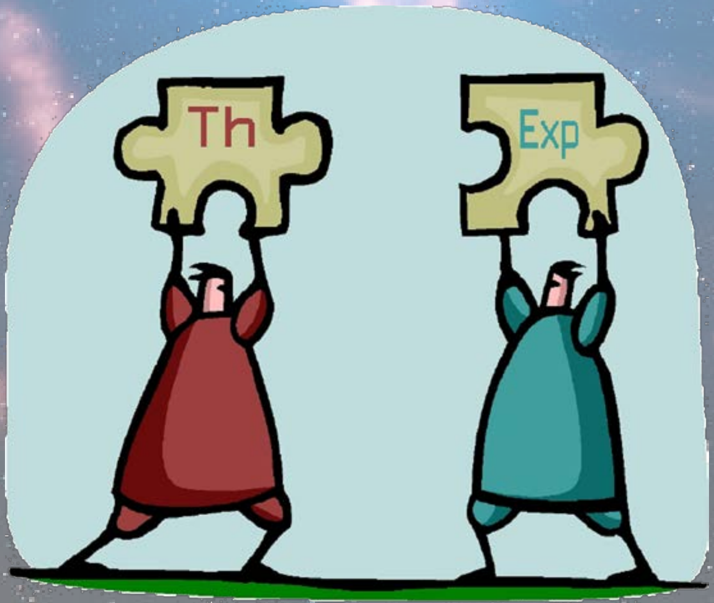
Santa *is* me!

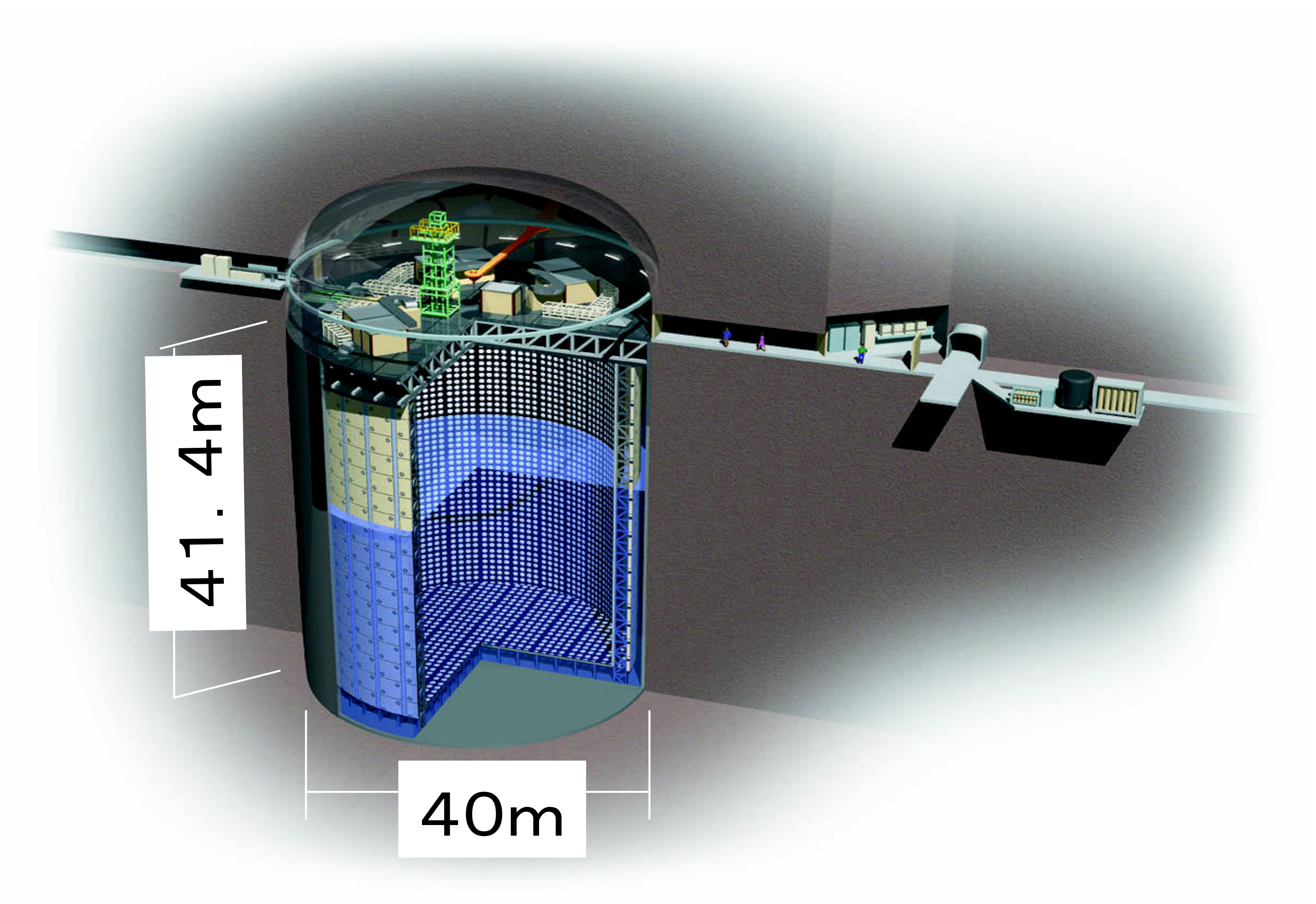
Like Santa,
I bring good things...
…including lots
of lanthanides for
all the good boys
and girls, like
my son Isaac.



This particular Santa has even gone pro -
performing for a paying audience of
1,317 in a Tokyo stage show!

- DSNB Experimental Challenges
  - Need a very large detector: >10 ktons fiducial volume for detection (~0.2 IBD events/yr/kton)
  - Must have very low background rates
  - Have to be able to identify individual, isolated events as arising from supernova explosions



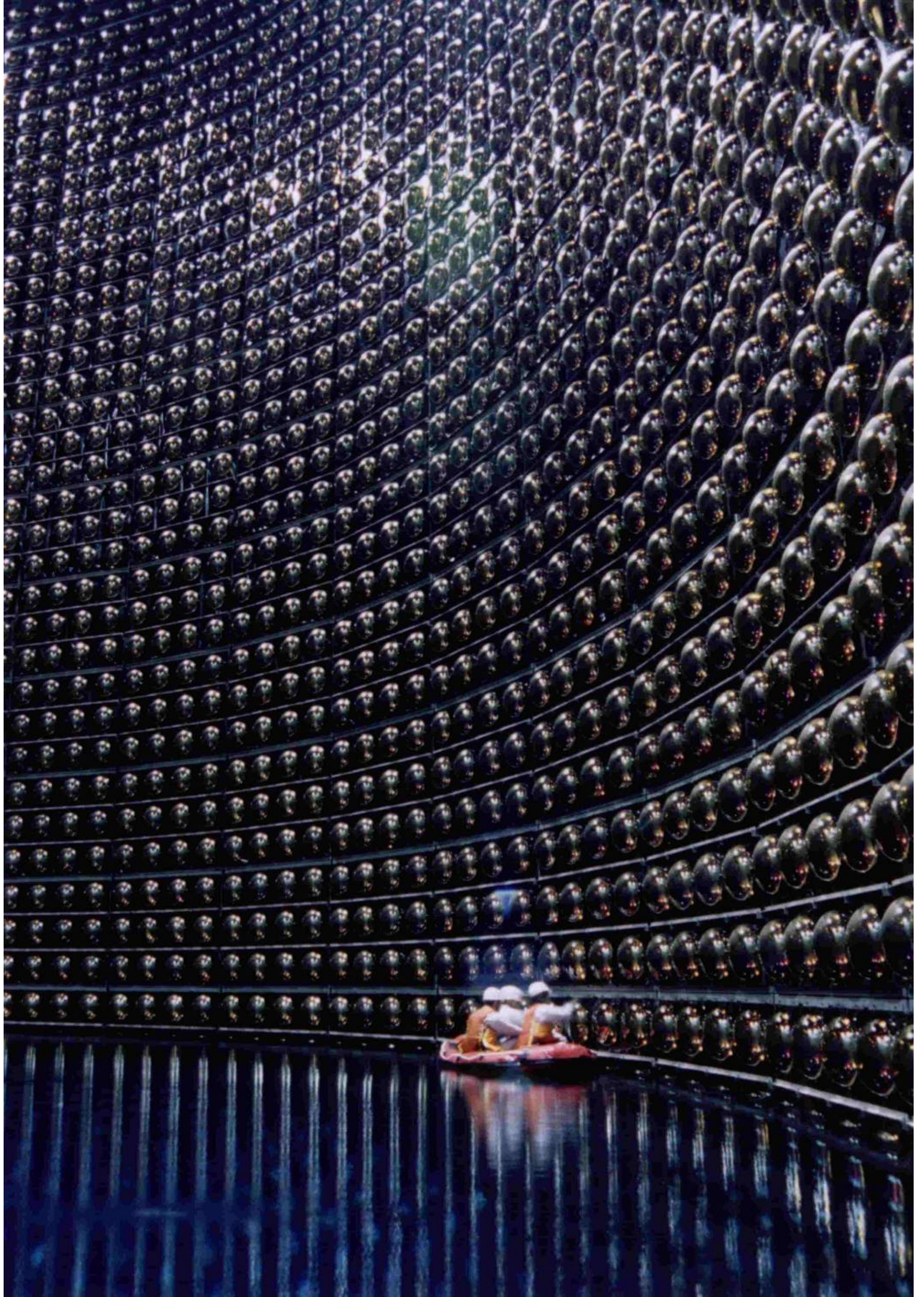


The Super-Kamiokande neutrino detector, in Mozumi, Japan.

50,000 tons of ultra-pure H_2O

13,000 light detectors

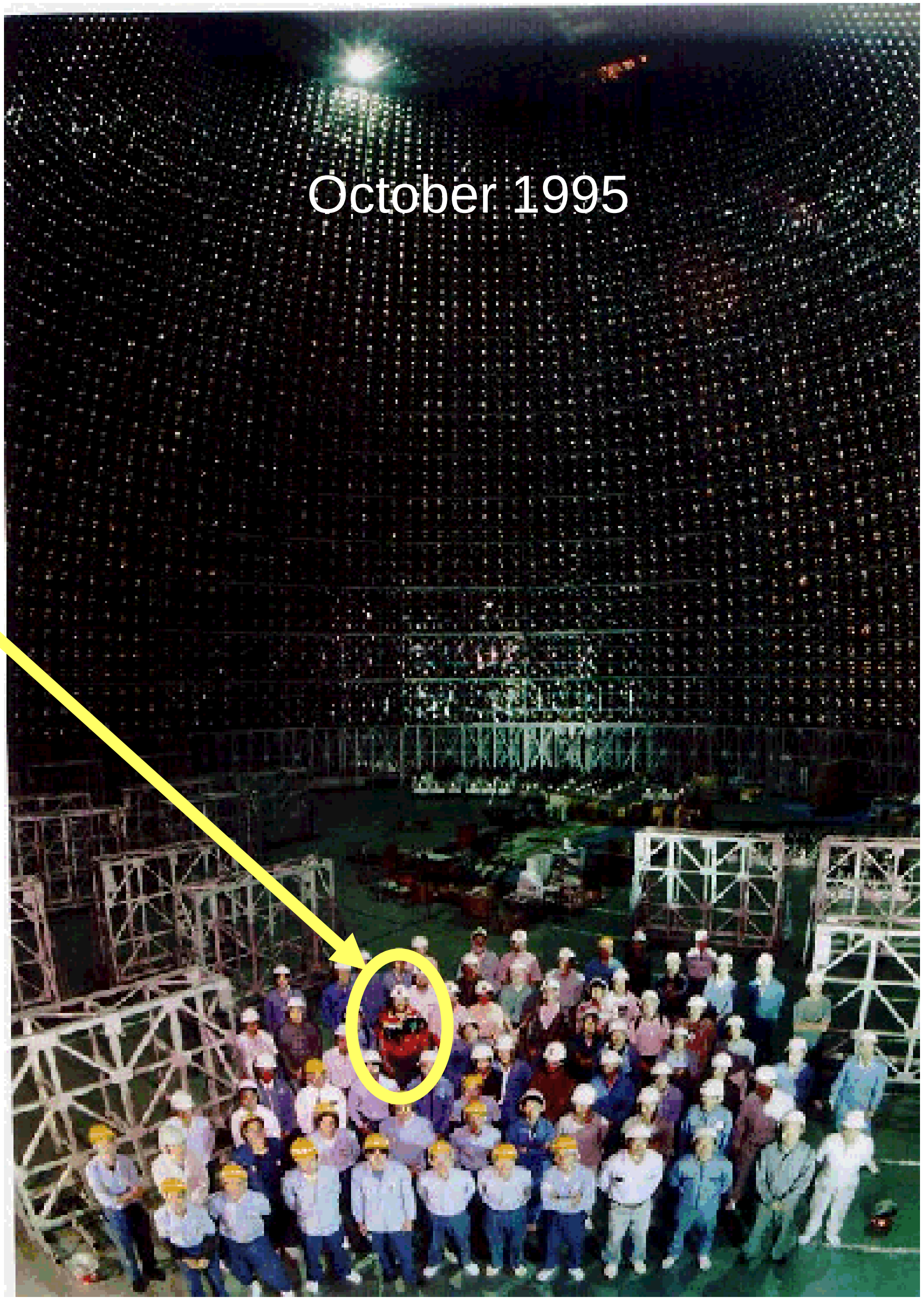
One kilometer underground



Observes particles from the Sun, supernovas, and cosmic rays

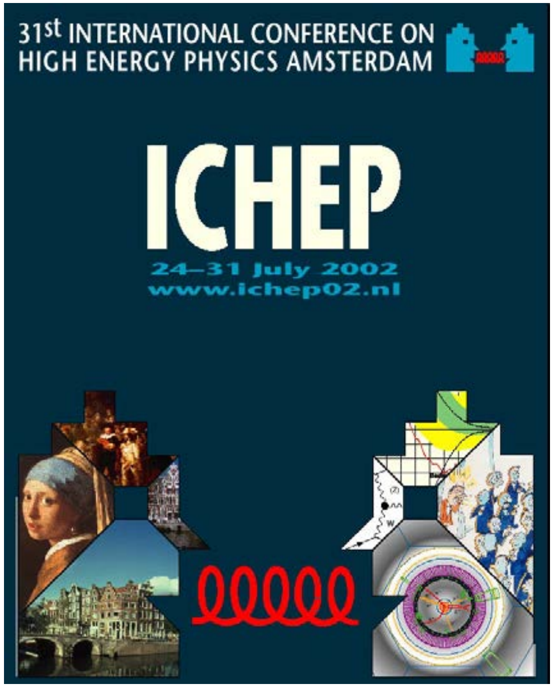
I’ve been a part of Super-K (and wearing brightly-colored shirts) from its very early days…

January 1996



<u>A tale of two cities:</u>

While attending Neutrino 2002 in Munich, John Beacom and I spent one long night talking about how to improve Super-K's recently released supernova relic neutrino analysis. We decided adding salt to the detector would help.



Then, at ICHEP 2002 in Amsterdam a couple of months later, I had an inspiring and exciting talk with Yoichiro Suzuki. I immediately sent John an email…

Date: Tue, 30 Jul 2002 03:45:09 -0700 (PDT)
From: Mark Vagins <vagins@danka.ps.uci.edu>
To: John Beacom <beacom@fnal.gov>
Subject: The briny, briny deep

Hey John,

I just spoke with Yoichiro Suzuki, who is also attending this meeting in Amsterdam. I brought up our scheme for making SK 1% salty.

He liked the idea a lot, and in fact said that salting SK was one of the future options he had been musing about. Naturally, he did say that we needed to carefully model a salty detector and get a feel for the true numbers.

He went on to say that the necessary water system modifications were possible, and that in the near future

"we must do something to get the new physics."

He also felt that 500 tons of salt was reasonable, saying to me,

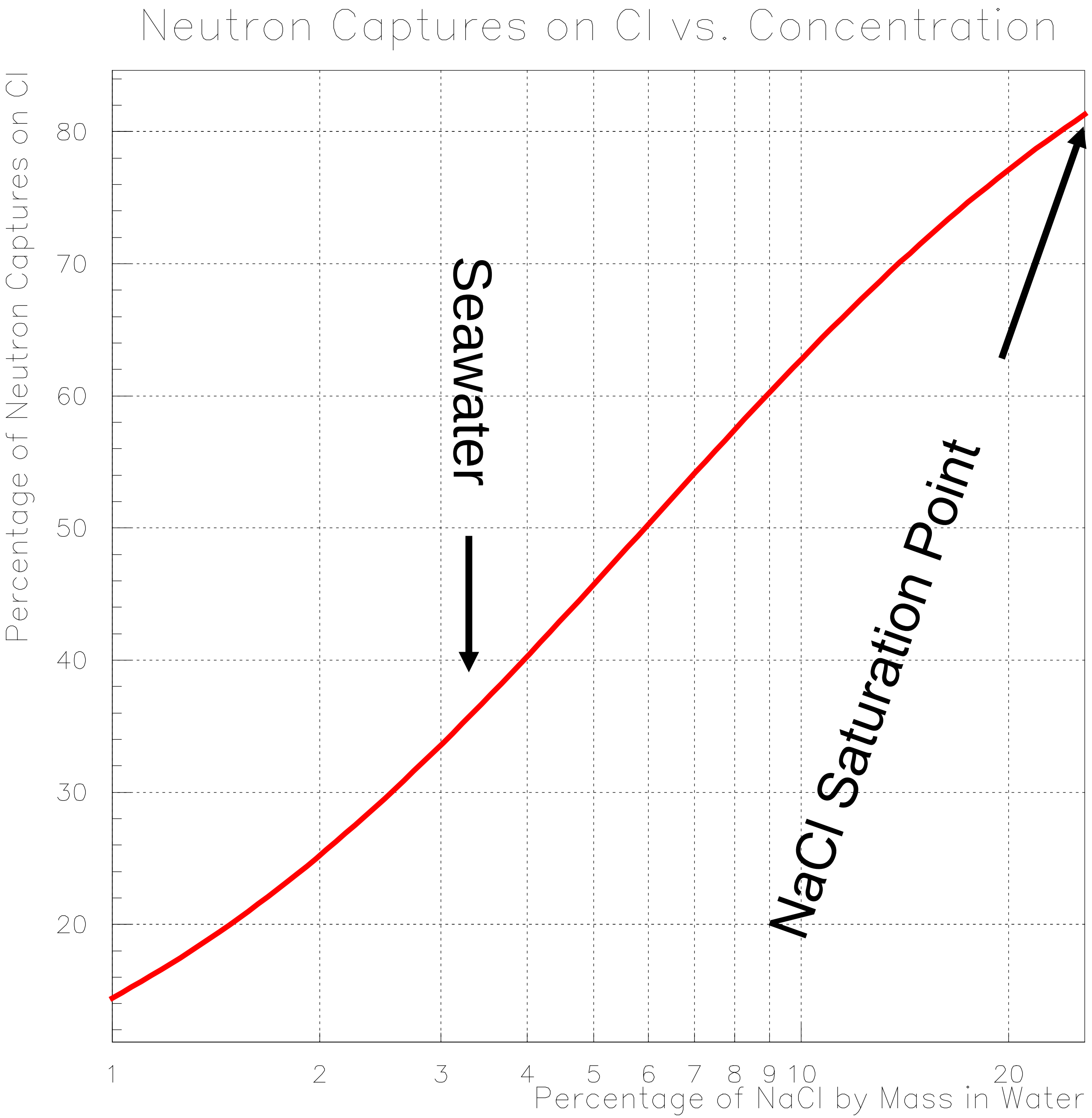
"It's just 50 truckloads - you can shovel it yourself!"

This is a very positive thing indeed (other than the part about my shoveling half a kiloton of salt myself).

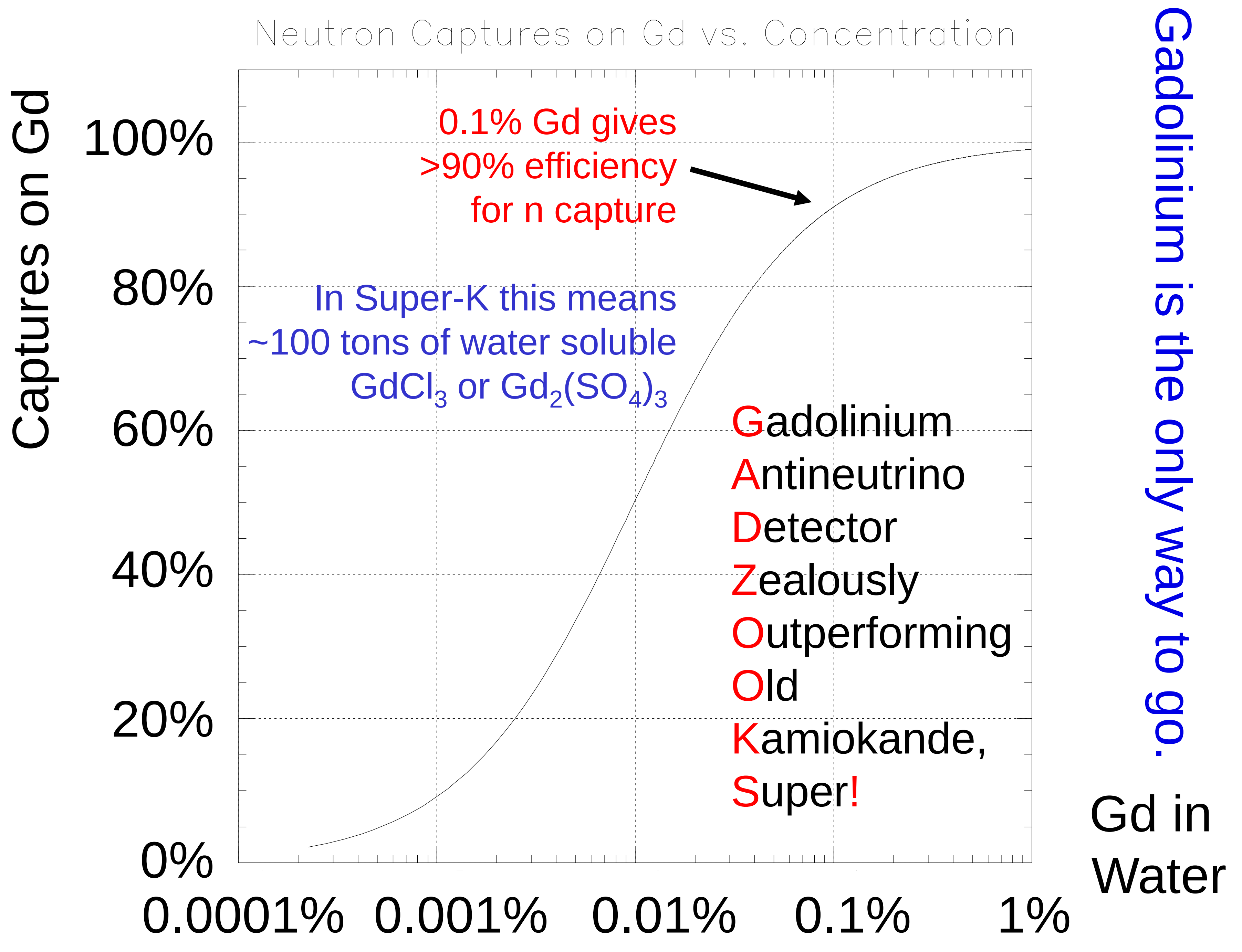
So, things sound pretty promising on this end. I wonder if it's worth putting out a phenomenological paper outlining how this will-salt-for-relics could work... it probably is, especially if there is a non-zero likelihood that SK will actually do something about it!

We must do something to get the new physics,
-Mark

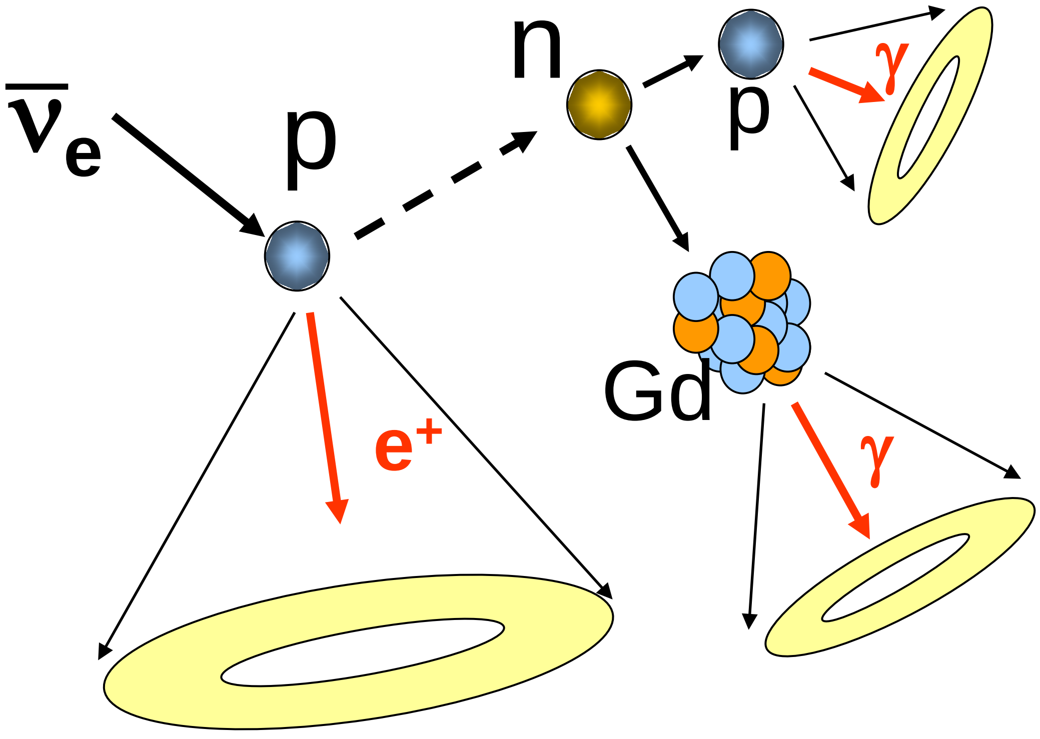
We got to work modeling a salty SK…



Regular salt **won't work** in Super-K!


Neutron Captures on Gd vs. Concentration
Captures on Gd
100%
80%
60%
40%
20%
0%
0.0001%
0.001%
0.01%
0.1%
1%
Gd in Water
0.1% Gd gives >90% efficiency for n capture
In Super-K this means ~100 tons of water soluble $GdCl_3$ or $Gd_2(SO_4)_3$
Gadolinium
Antineutrino
Detector
Zealously
Outperforming
Old
Kamiokande,
Super!
Gadolinium is the only way to go.

Inverse Beta Decay with 0.1% Gadolinium



Possibility 1: 10% or less

$n+p \rightarrow d + \gamma$

2.2 MeV γ-ray

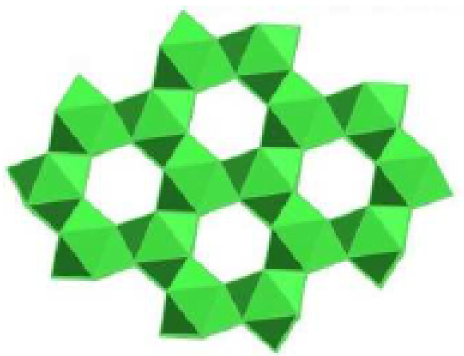
Possibility 2: 90% or more

$n+Gd \rightarrow \sim 8\text{MeV}\ \gamma$

$\Delta T = \sim 30\ \mu\text{sec}$

$\overline{\nu}_e$ can be positively identified by delayed coincidence.

Gadzooks!



[A Serious SK Upgrade Suggestion]

Mark Vagins
University of California, Irvine

Osawano
November 11, 2002

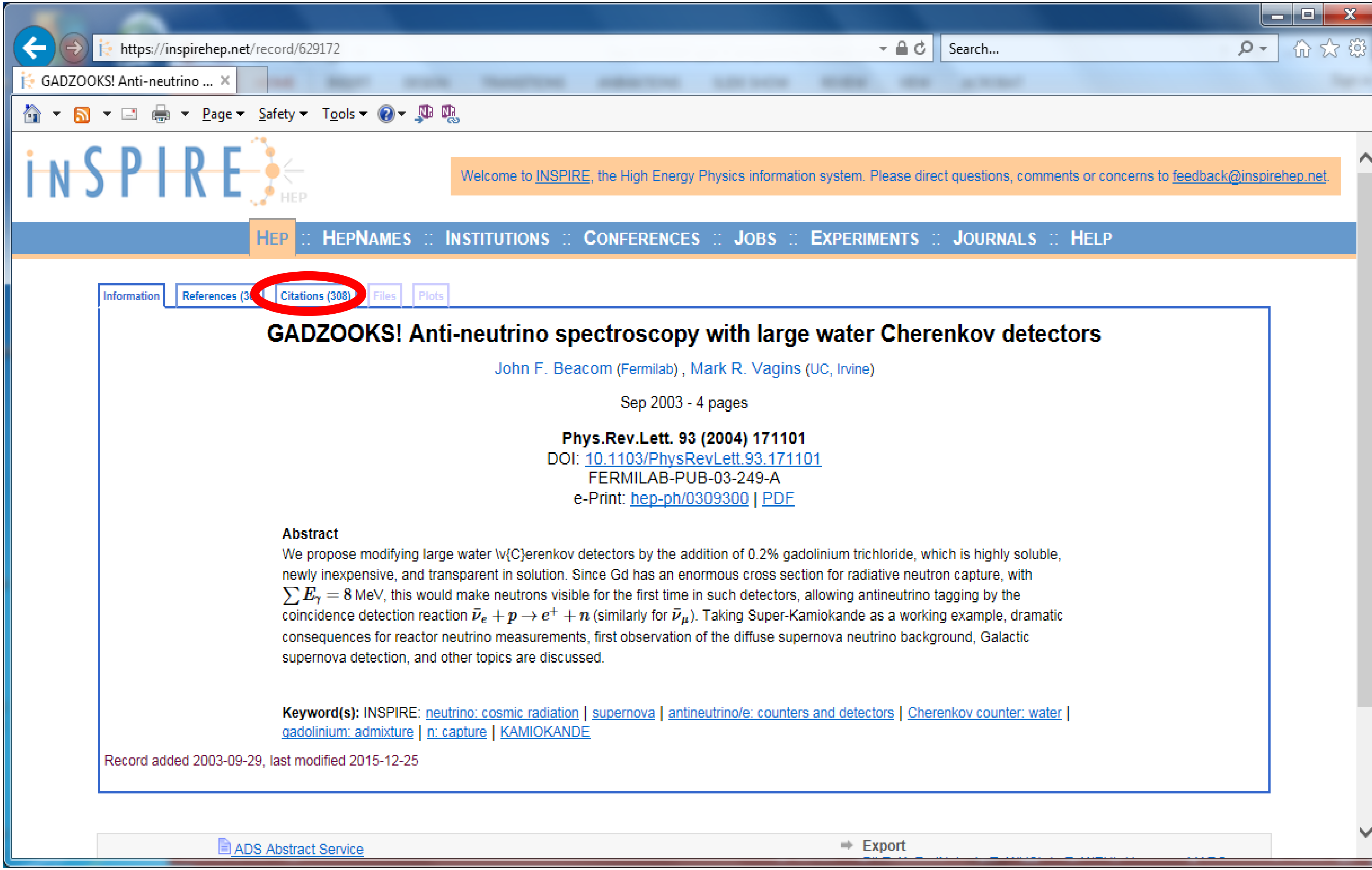
Here's the very first transparency (i.e., what we older folks used before PowerPoint but after glass slides) I ever showed on the topic…

fifteen years ago.

Please note the subtitle:

"A Serious SK Upgrade Suggestion"

John and I did eventually get our paper out…



As of yesterday night, it had 308 citations.

Super-K currently records just <u>three fake neutrino-like singles (events) per cubic meter per year,</u> but this still overwhelms the faint DSNB signal.

[K. Bays *et al.*, Phys.Rev. D85 (2012) 052007].

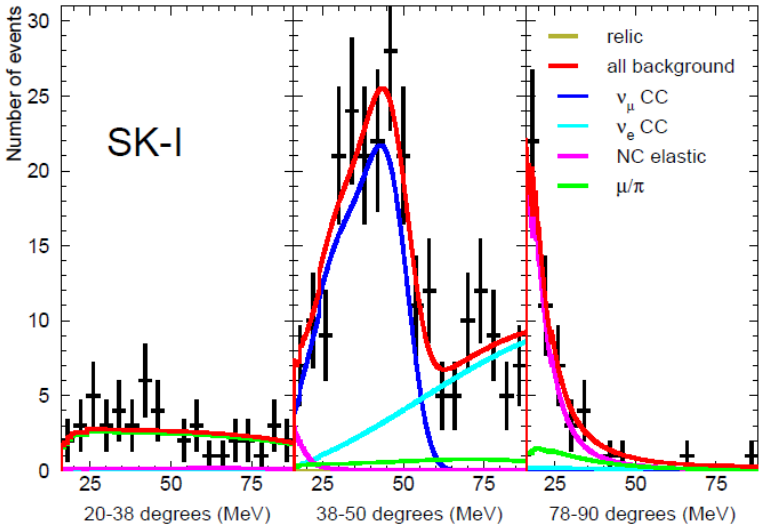
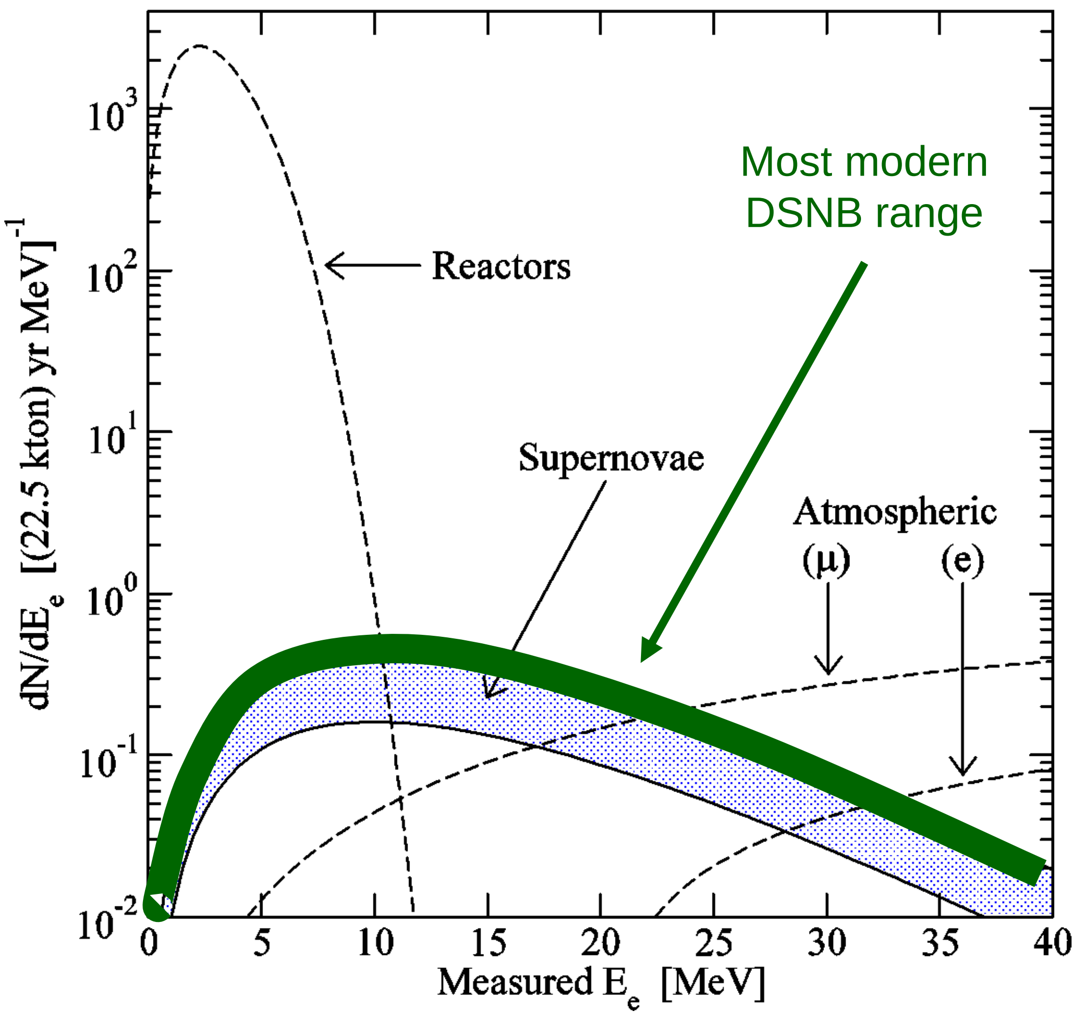


FIG. 14. SK-I LMA best fit result. The relic best fit is negative, so a relic fit of 0 is shown.

The Gd tagging technique will greatly reduce the fakes, allowing event-by-event identification of true SN events.

We would expect to collect an SN1987A-scale neutrino sample in Super-K <u>every two years.</u>

Here's what the coincident signals in Super-K with $GdCl_3$ or $Gd_2(SO_4)_3$ will look like (energy resolution is applied):



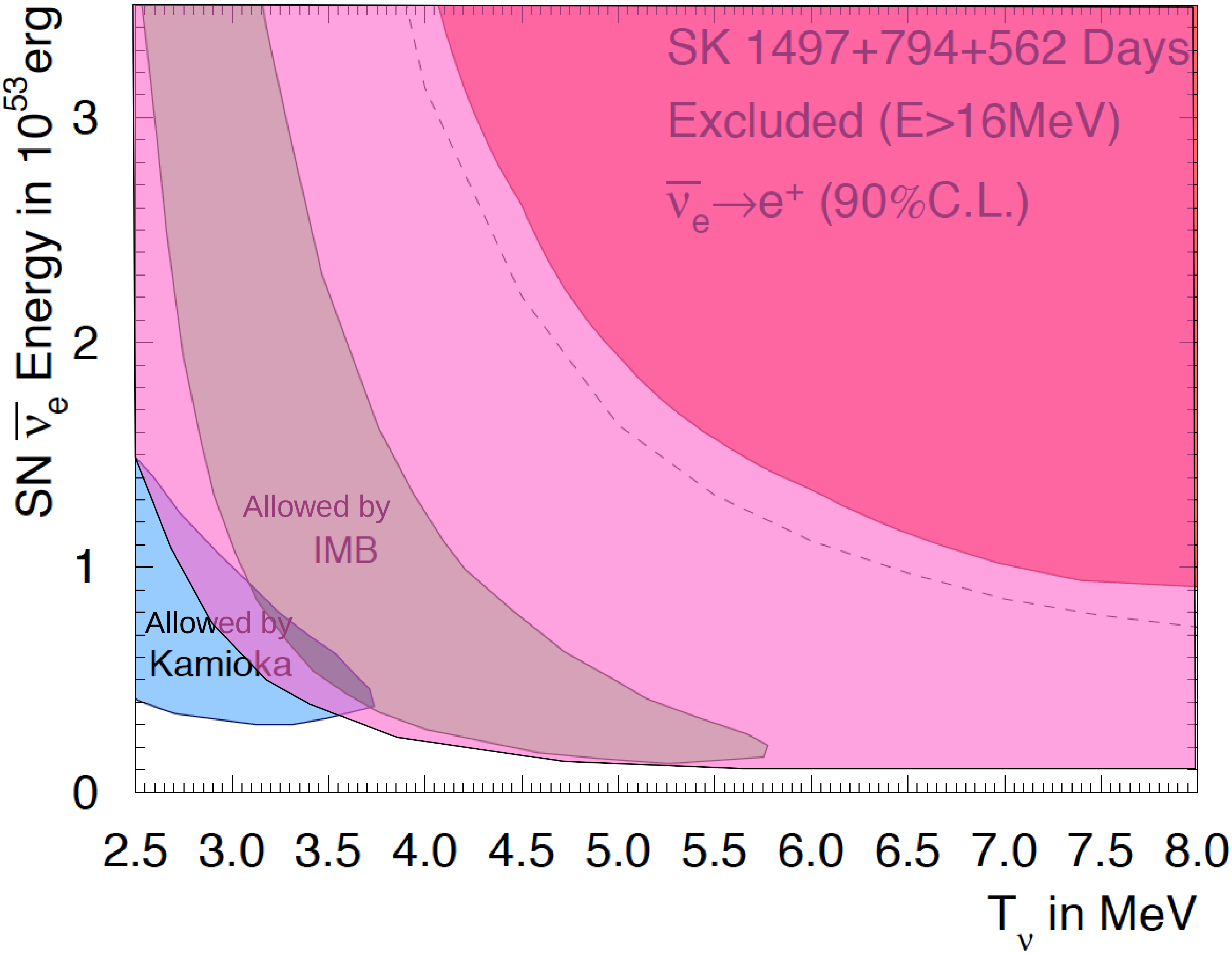
$\bar{\nu}_e + p \rightarrow e^+ + n$

spatial and temporal separation between prompt e^+ Cherenkov light and delayed Gd neutron capture gamma cascade:

λ=~4cm, τ=~30μs

→ A few clean events/yr in Super-K with Gd

DSNB Sensitivity Region After Six Years With Gd In SK



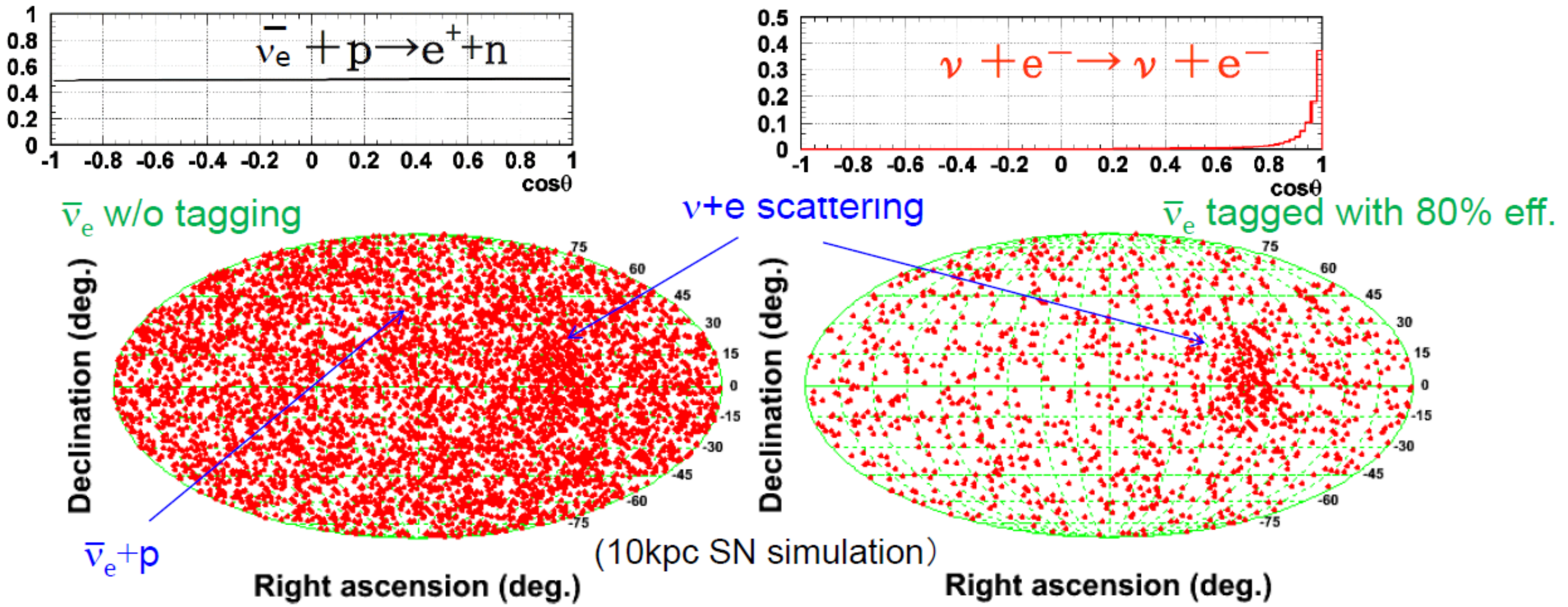
In the case of a galactic supernova, having $Gd_2(SO_4)_3$ in Super-K will provide many important benefits:

- Allows the exact $\bar{\nu}_e$ flux, energy spectrum, and time profile to be determined via the extraction of a tagged, pure sample of inverse beta events.
- Instantly identifies a burst as genuine via “Gd heartbeat”.
- Doubles the ES pointing accuracy. Error circle cut by 75%.
- Helps to identify the other neutrino signals, especially the weak neutronization burst of ν_e.
- Enables a search for very late time black hole formation.
- Provides for very early warning of the most spectacular, nearby explosions so we can be sure not to miss them.

Supernovas and Gd loading:

Not only for DSNB

- If $\bar{\nu}_e$ can be tagged, directional events (ν+e scattering events) are enhanced. Pointing accuracy should be improved. For 10kpc SN ~5° → ~3° (@90%C.L.)



- Sensitive to $\bar{\nu}_e$ of Si burning phase. 800~2000 events/day for pre-supernova at 200pc

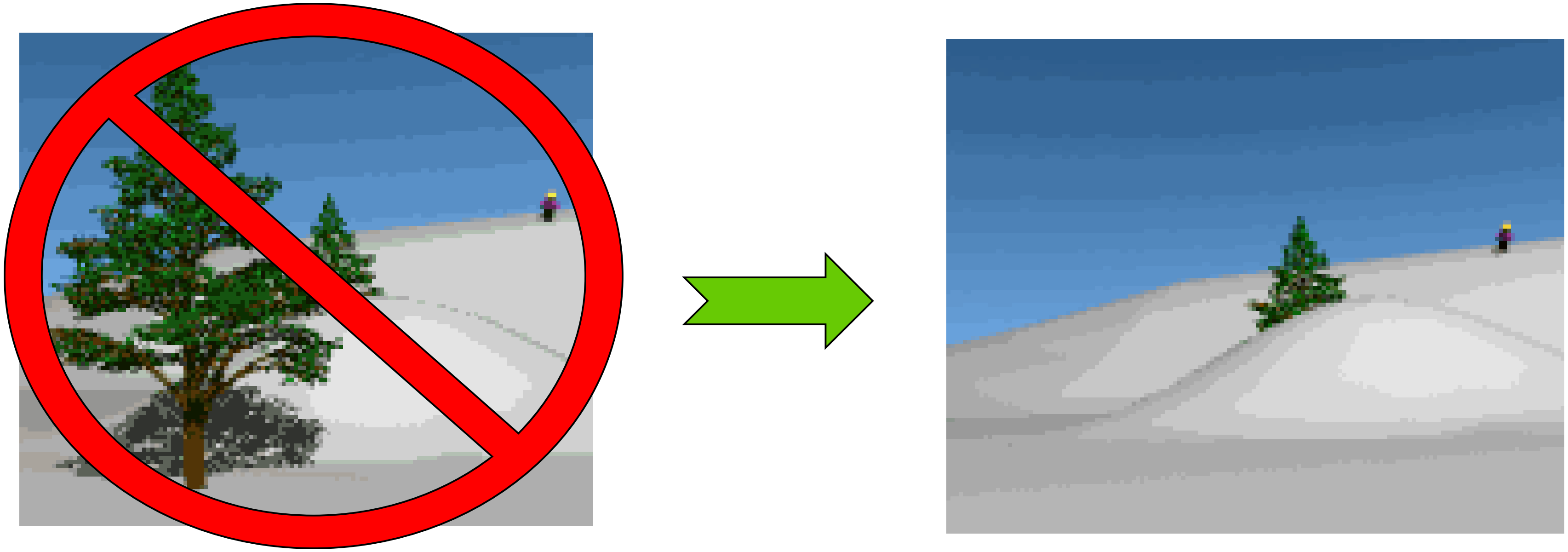
Neutron tagging from Gd loading will also improve SK's existing proton decay searches, atmospheric, solar, and long-baseline neutrino analyses. It will make reactor neutrino studies possible in SK, as well.

Now, John and I never wanted to merely propose a new technique – we wanted to make it work!

[Snowbird photo by A. Kusenko]

Suggesting a major modification of one of the world's leading neutrino detectors may not be the easiest route…

…and so to avoid wiping out, some careful hardware studies are needed.



- What does gadolinium do the Super-K tank materials?
- Will the resulting water transparency be acceptable?
- Any strange Gd chemistry we need to know about?
- How will we filter the SK water but retain dissolved Gd?

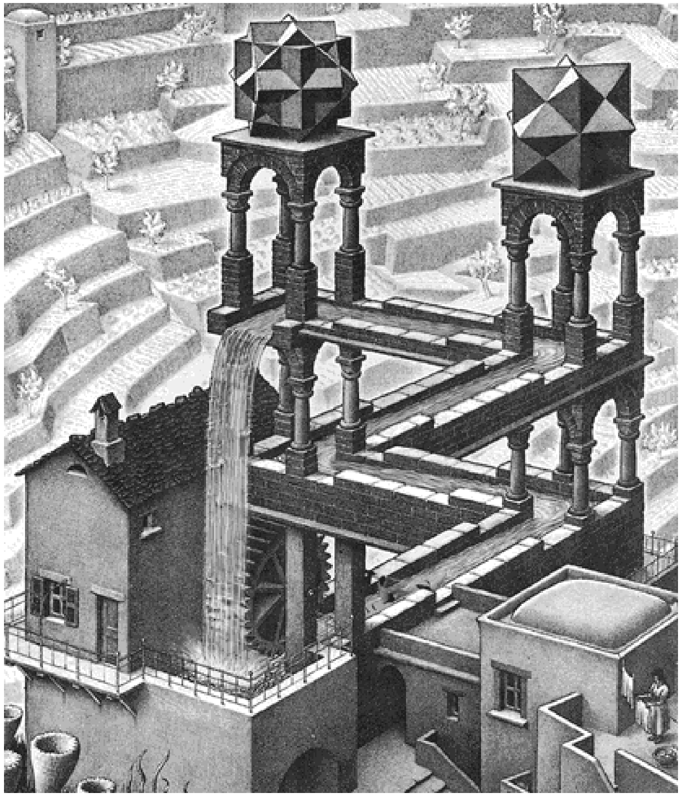
As a matter of fact, I very rapidly made two discoveries regarding $GdCl_3$ while carrying a sample from Los Angeles to Tokyo:

1) $GdCl_3$ is quite opaque to X-rays
2) Airport personnel get <u>very</u> upset when they find a kilogram of white powder in your luggage

The Essential Magic Trick

→ We must keep the water in any Gd-loaded detector perfectly clean… *without removing the dissolved Gd.*

→ I've developed a new technology:
"Molecular Band-Pass Filtration"
Staged nanofiltration selectively retains Gd while removing impurities.



Amazingly, the darn thing works!

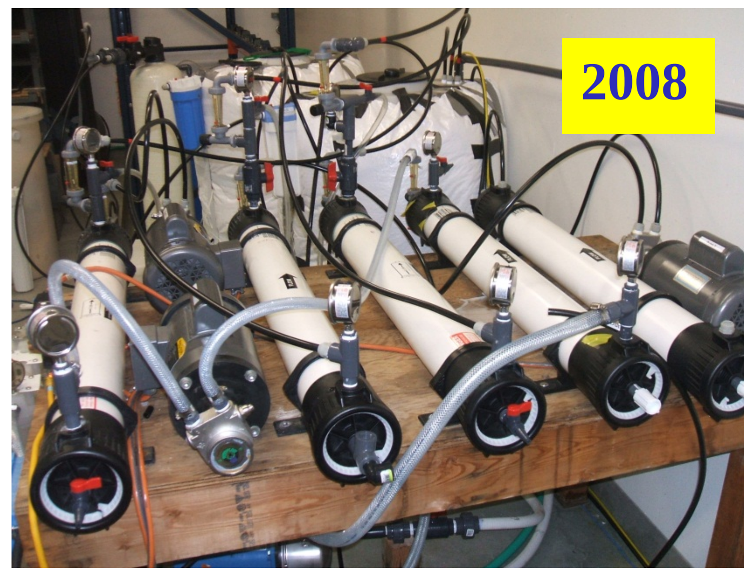
This technology will support a variety of applications, such as:

→ Supernova neutrino and proton decay searches

→ Remote detection of clandestine fissile material production

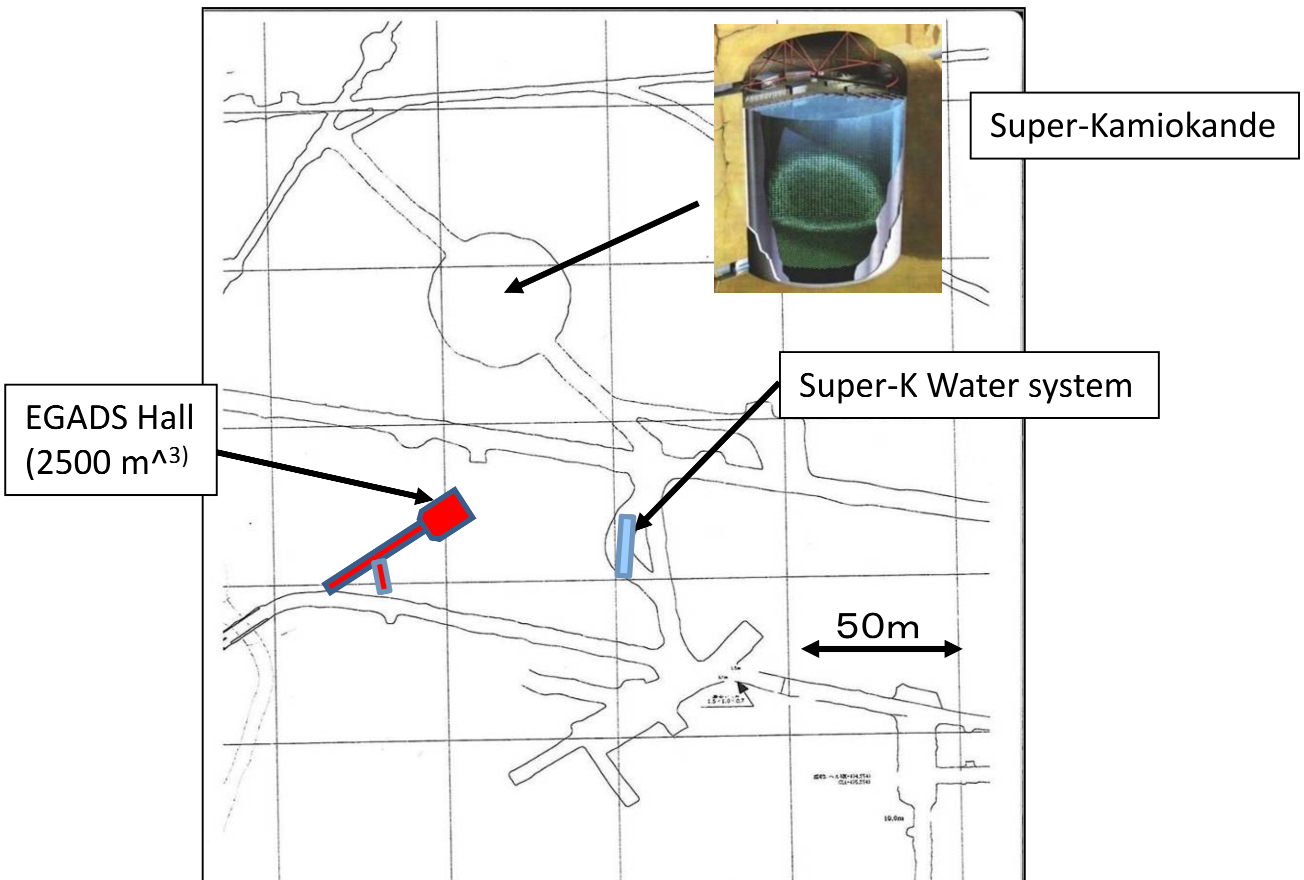
→ Efficient generation of clean drinking water without electricity

The experimental setup at UCI kept getting more complicated, until we knew enough for a large-scale test: EGADS.



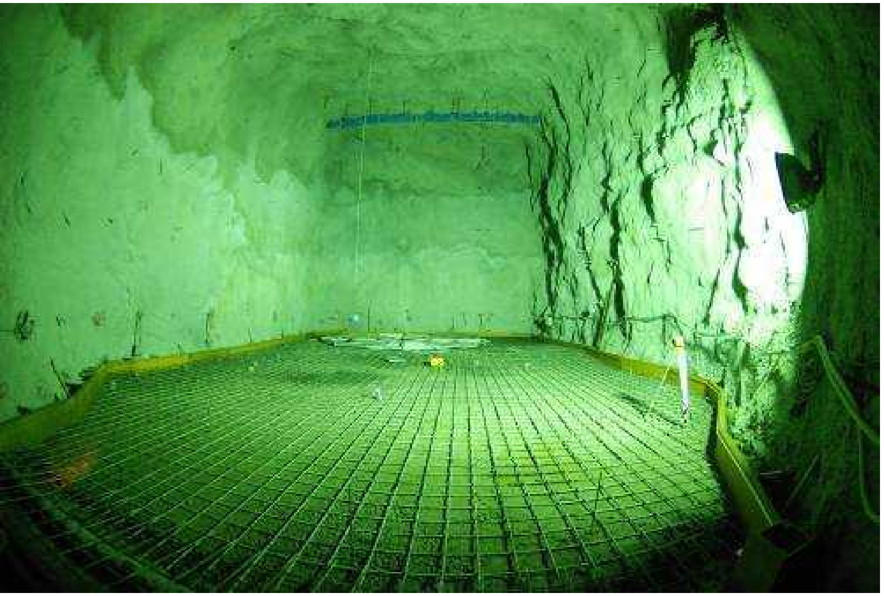
To confirm that Gd loading will work in Super-K, a dedicated Gd test facility was built in the Kamioka mine, complete with its own water filtration system, 50-cm PMT's, and DAQ electronics.

This 200 ton-scale R&D project is called EGADS – Evaluating Gadolinium's Action on Detector Systems.



Hall E and EGADS

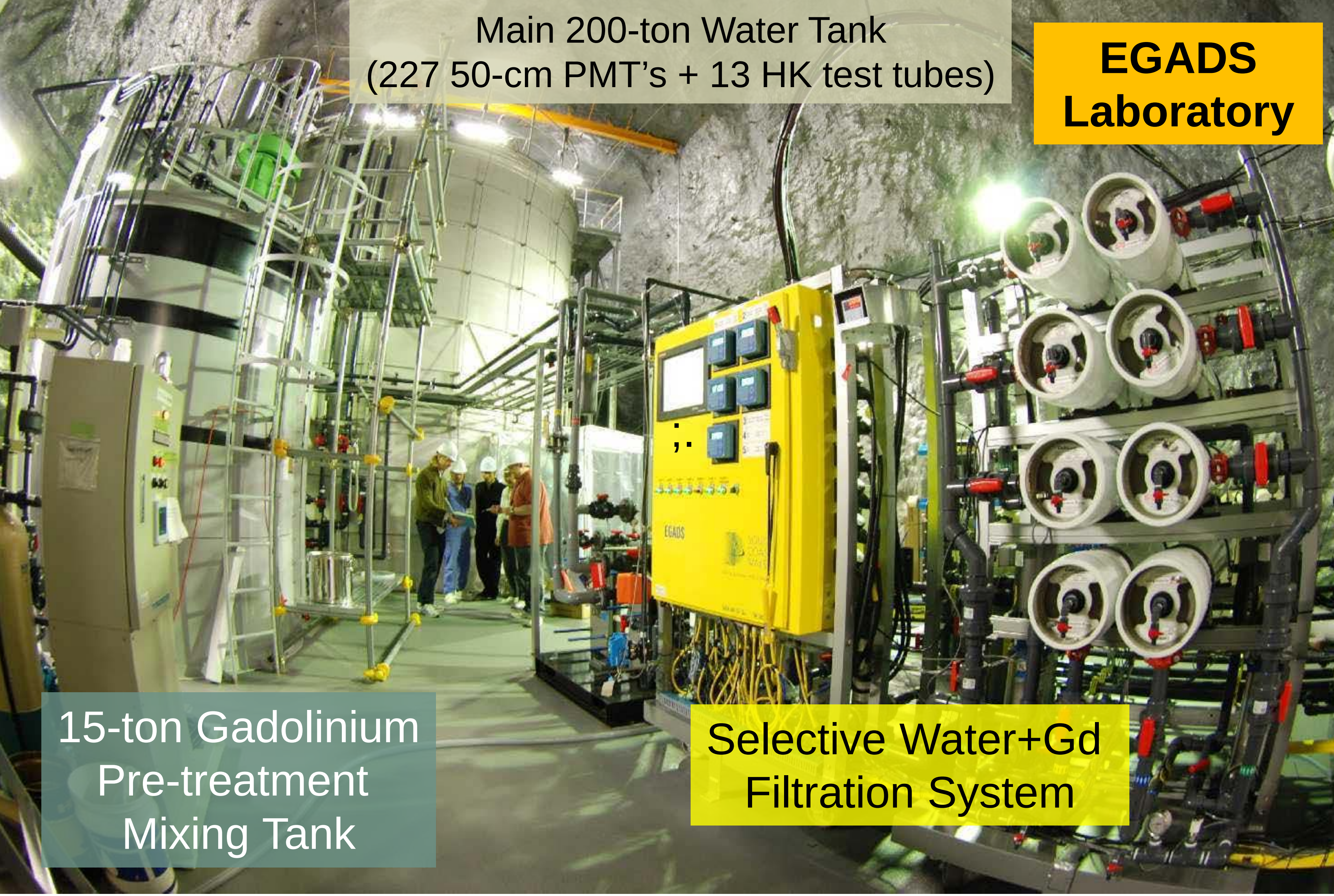
12/2009



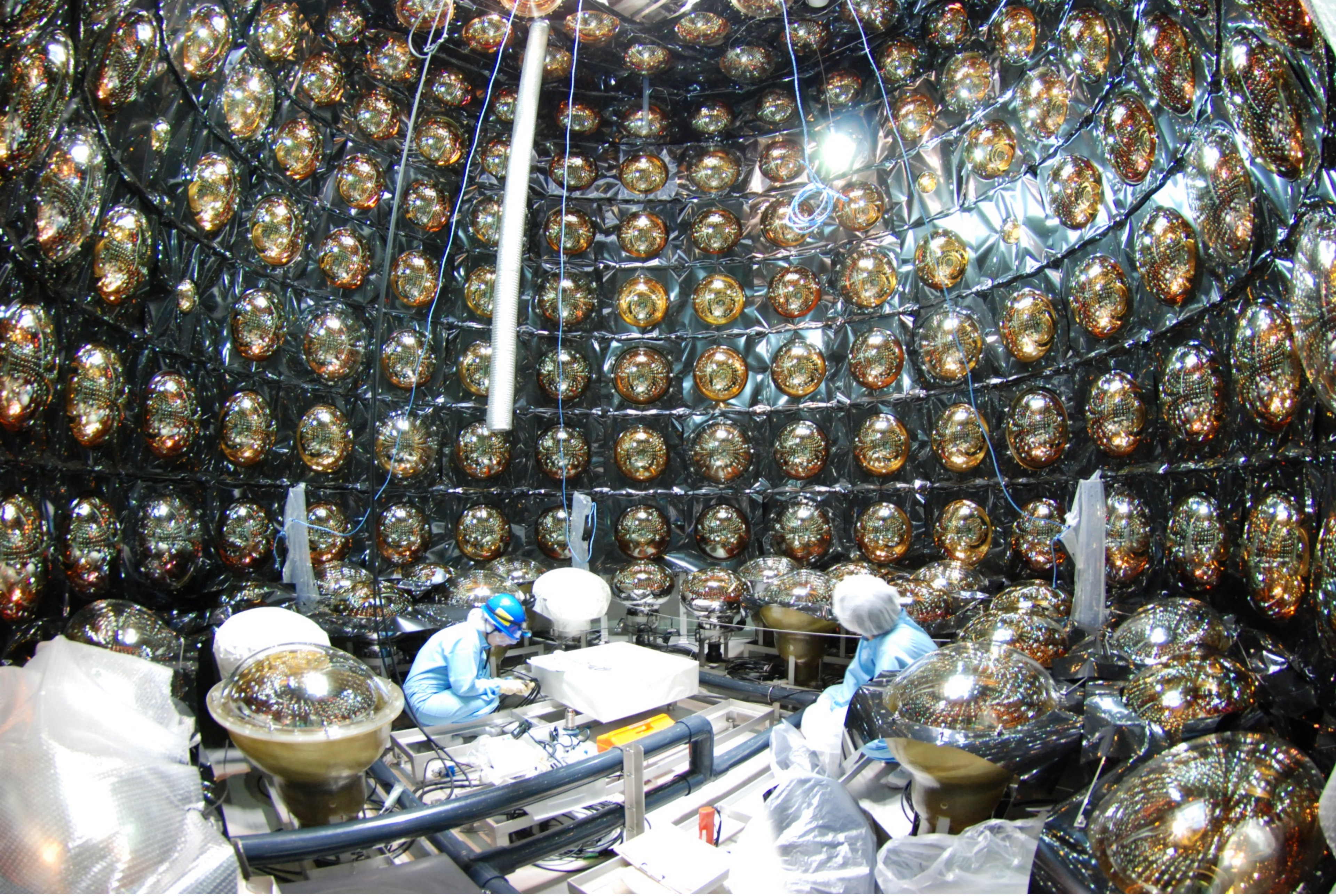
2/2010

6/2010

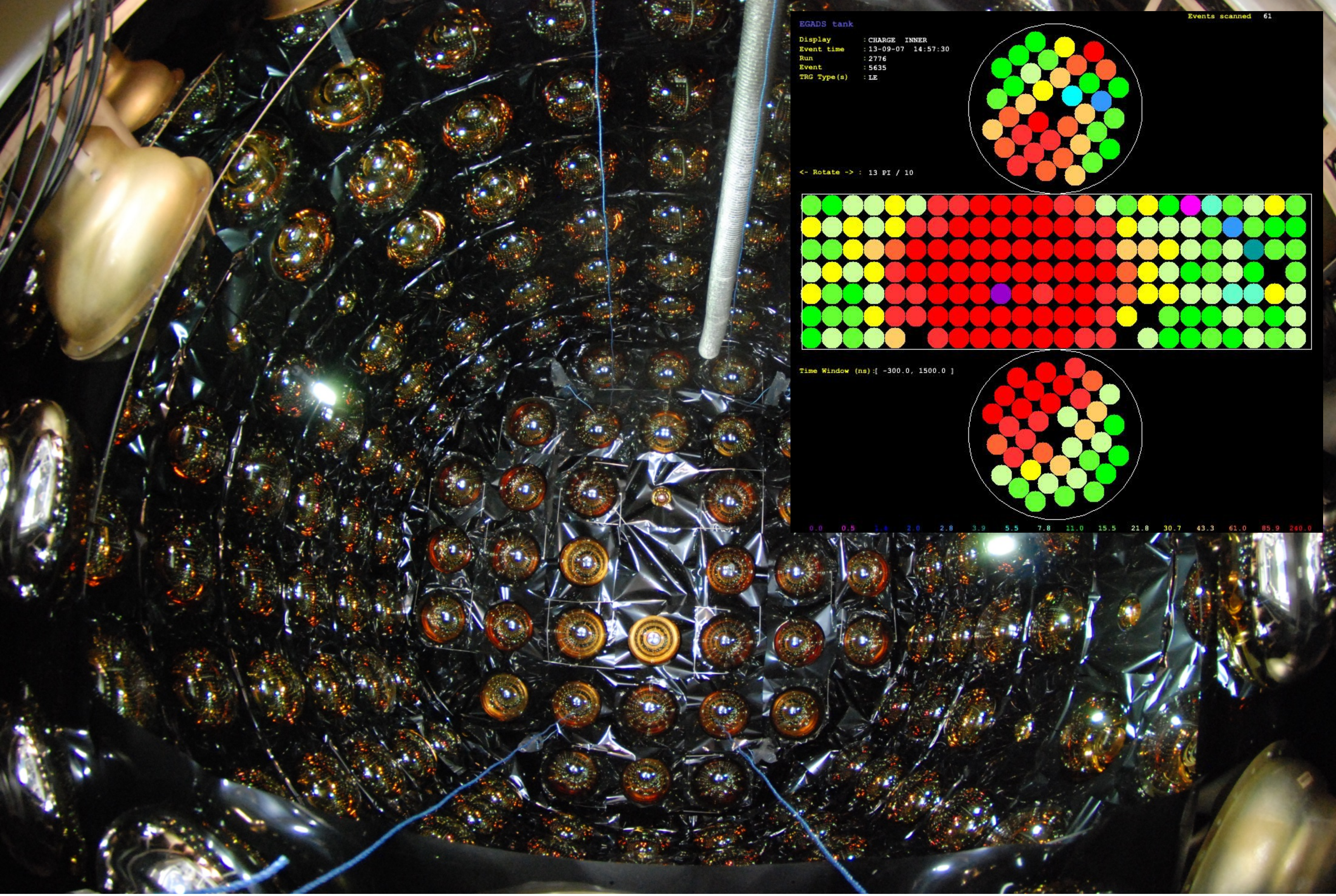
12/2010



Worldwide, over $20,000,000 dollars (!) has been spent developing and proving the viability of the Gd-in-water concept.



Working Inside the EGADS Tank; August 2013



Looking Down Into the Completed EGADS Detector; August 2013

Insert: Event Display of a Downward-Going Cosmic Ray Muon

May, 2014

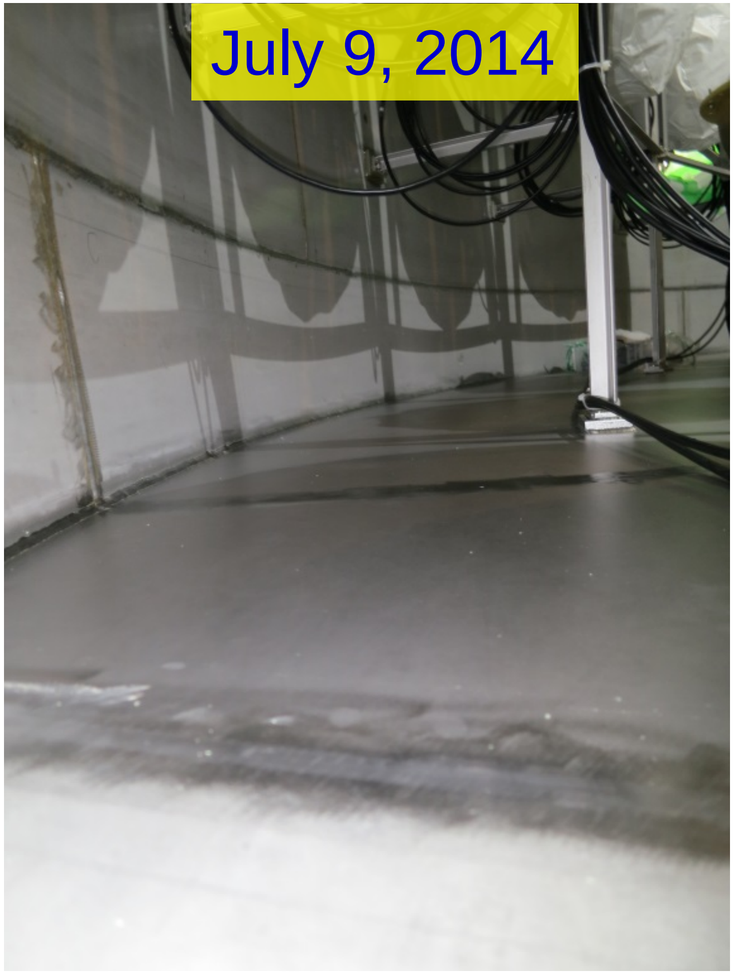
We've had just one little problem…

A trusted Japanese vendor had assured us this structural wire was 304 stainless steel based on the manufacturing company's claims, but it most certainly was not. Rust went everywhere inside the tank!

This wire also has a core made of Nylon 6: not designed for water.

The road to recovery

Having discovered this problem in April 2014, we then spent the next five months cleaning up the EGADS detector.



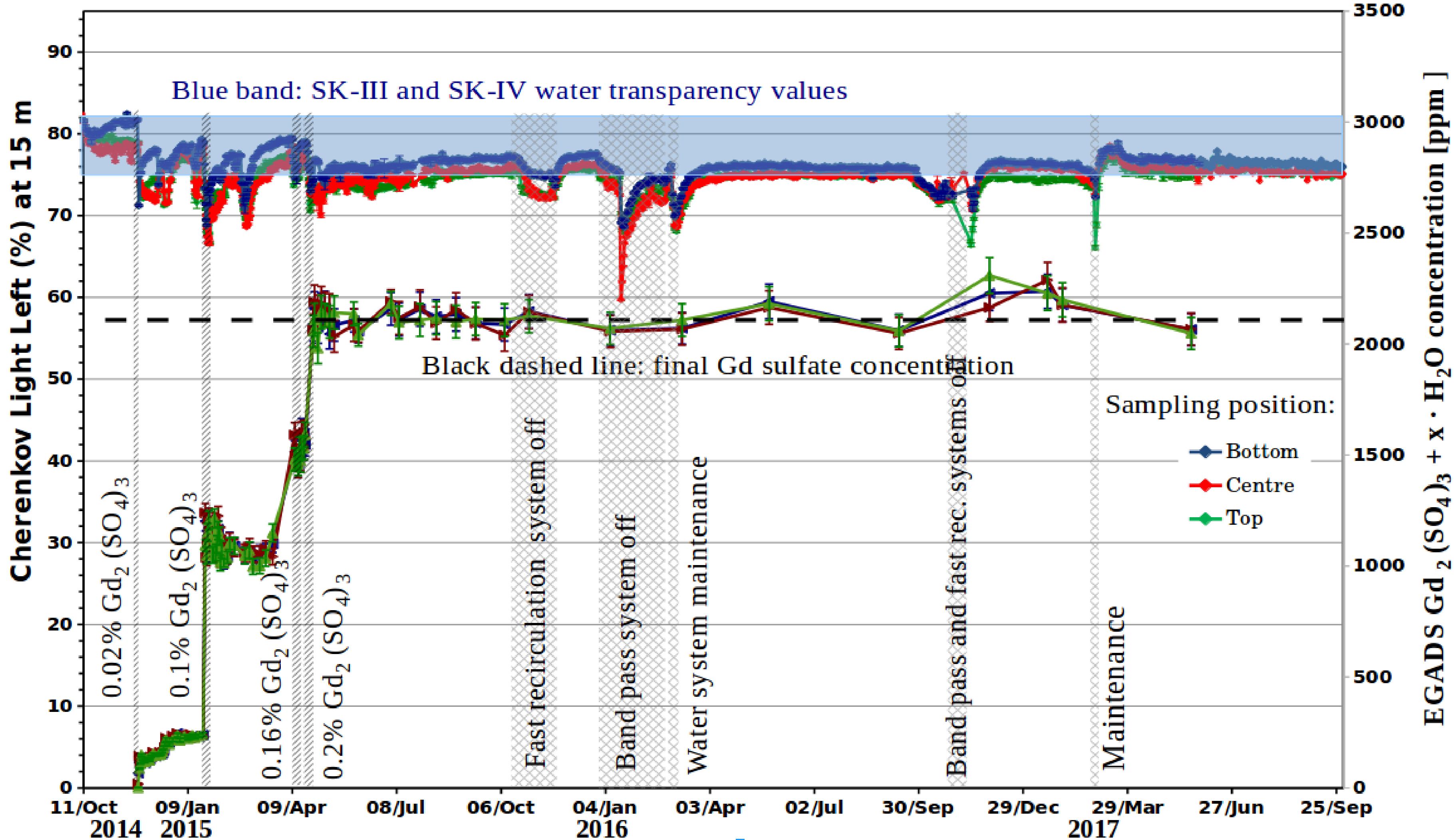
The road to recovery

Sept. 18, 2014

Clean up the tank?

Mission:Possible!

Light @ 15 meters and Gd conc. in the 200-ton EGADS tank

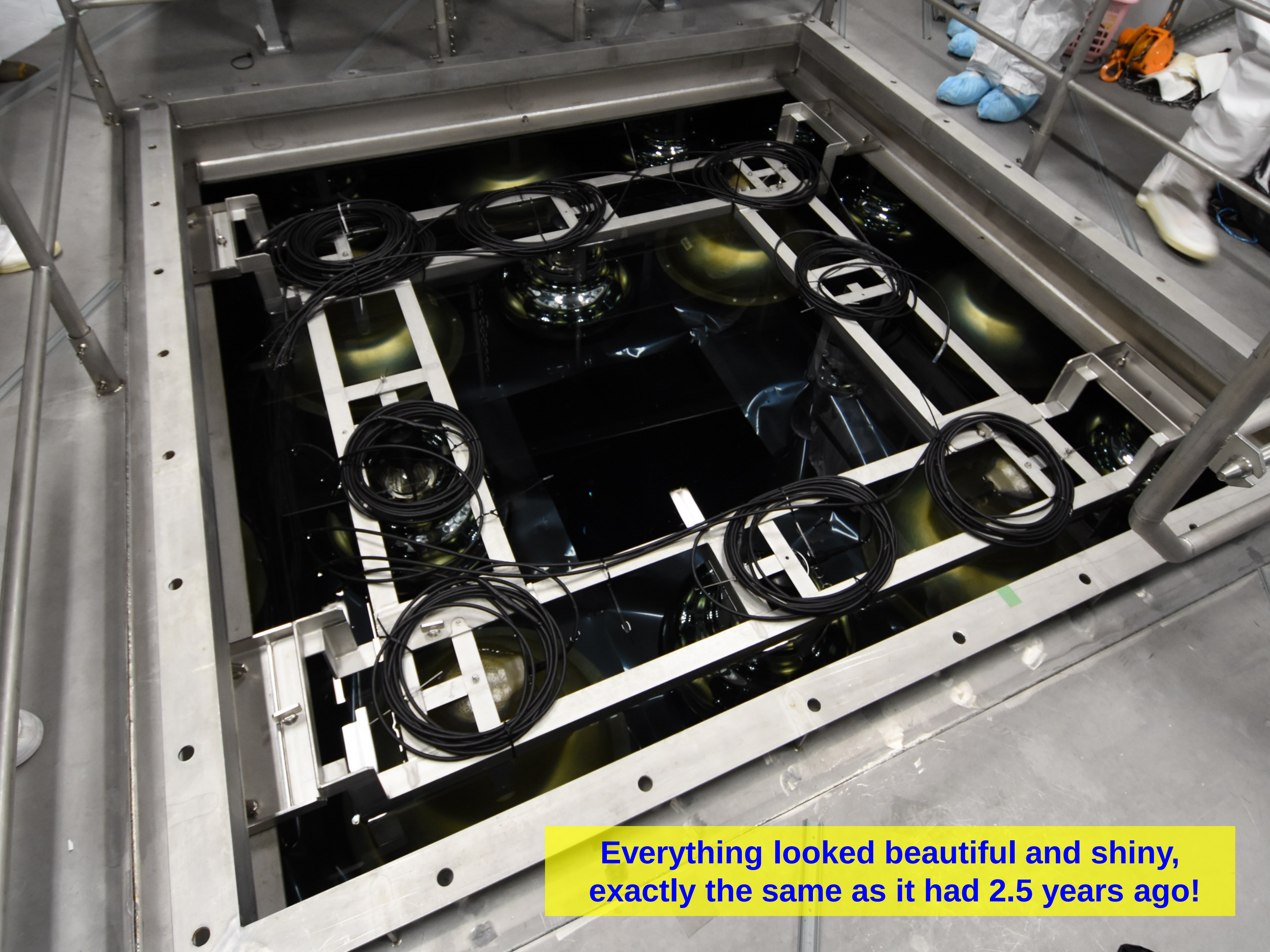


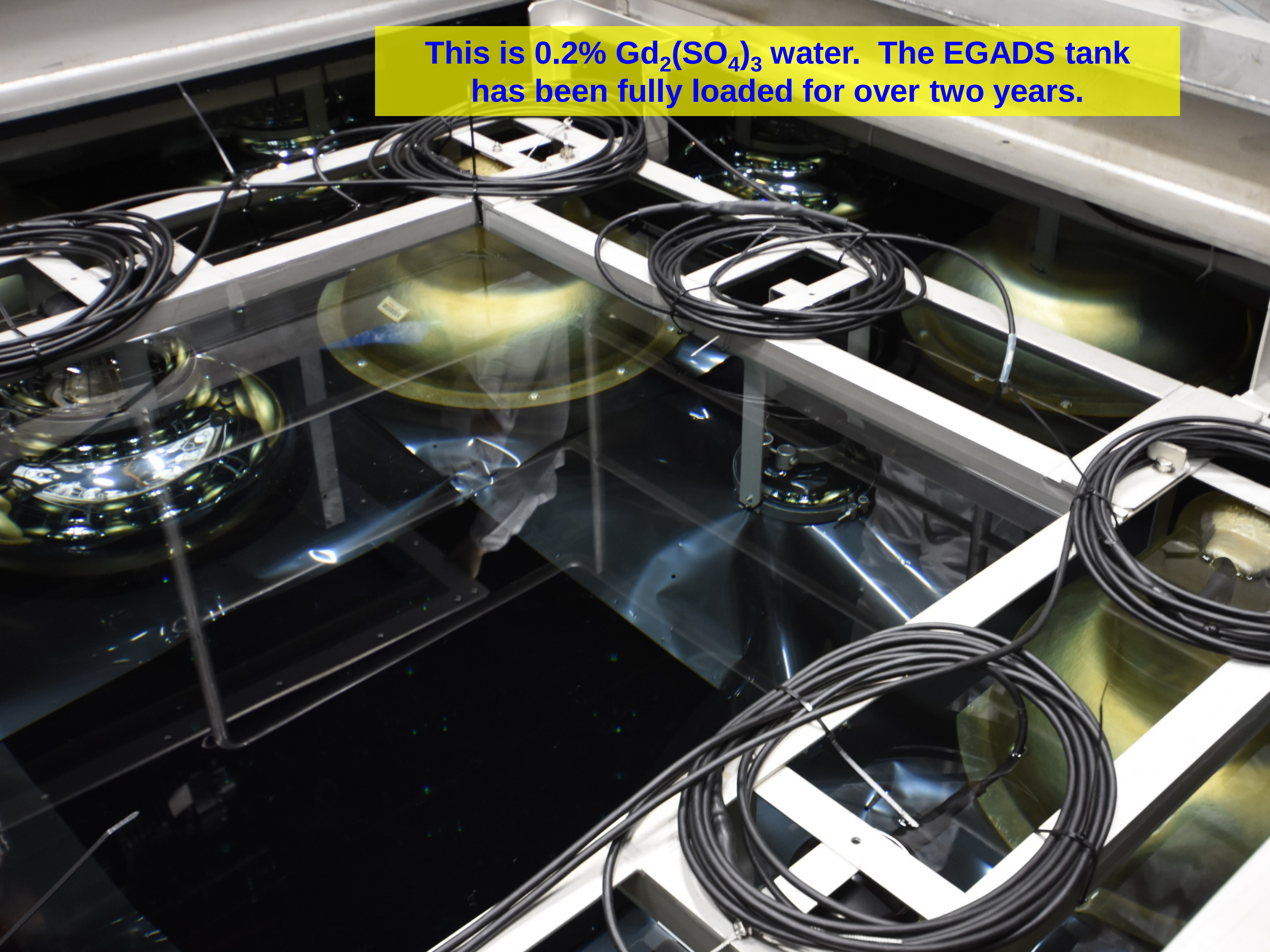
After more than two years at full Gd loading, during stable operations EGADS water transparency remains within the SK ultrapure range.

→ No detectable loss of Gd after more than 500 complete turnovers. ←

On May 16th, 2017, we opened the EGADS 200-ton tank. This was to be our first look inside since October 2014.

The big reveal - opening the square hatch; May 16th, 2017

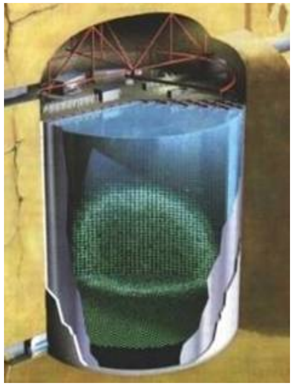

Everything looked beautiful and shiny,
exactly the same as it had 2.5 years ago!


This is 0.2% $Gd_2(SO_4)_3$ water. The EGADS tank
has been fully loaded for over two years.

After years of testing and study

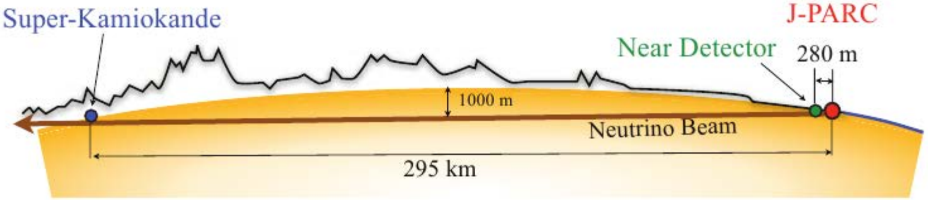
– culminating in these powerful EGADS results –

no technical showstoppers have been encountered. And so…

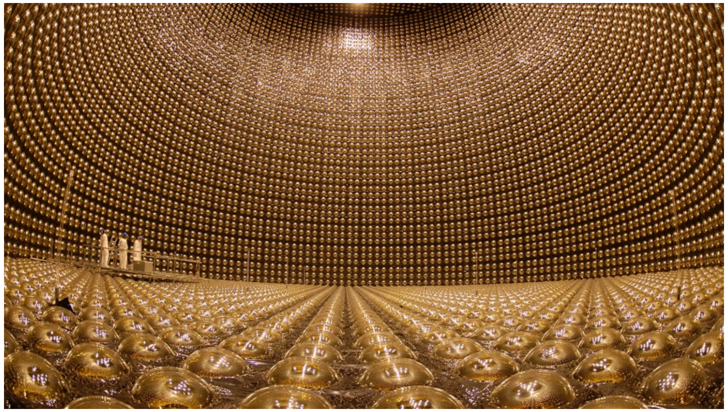


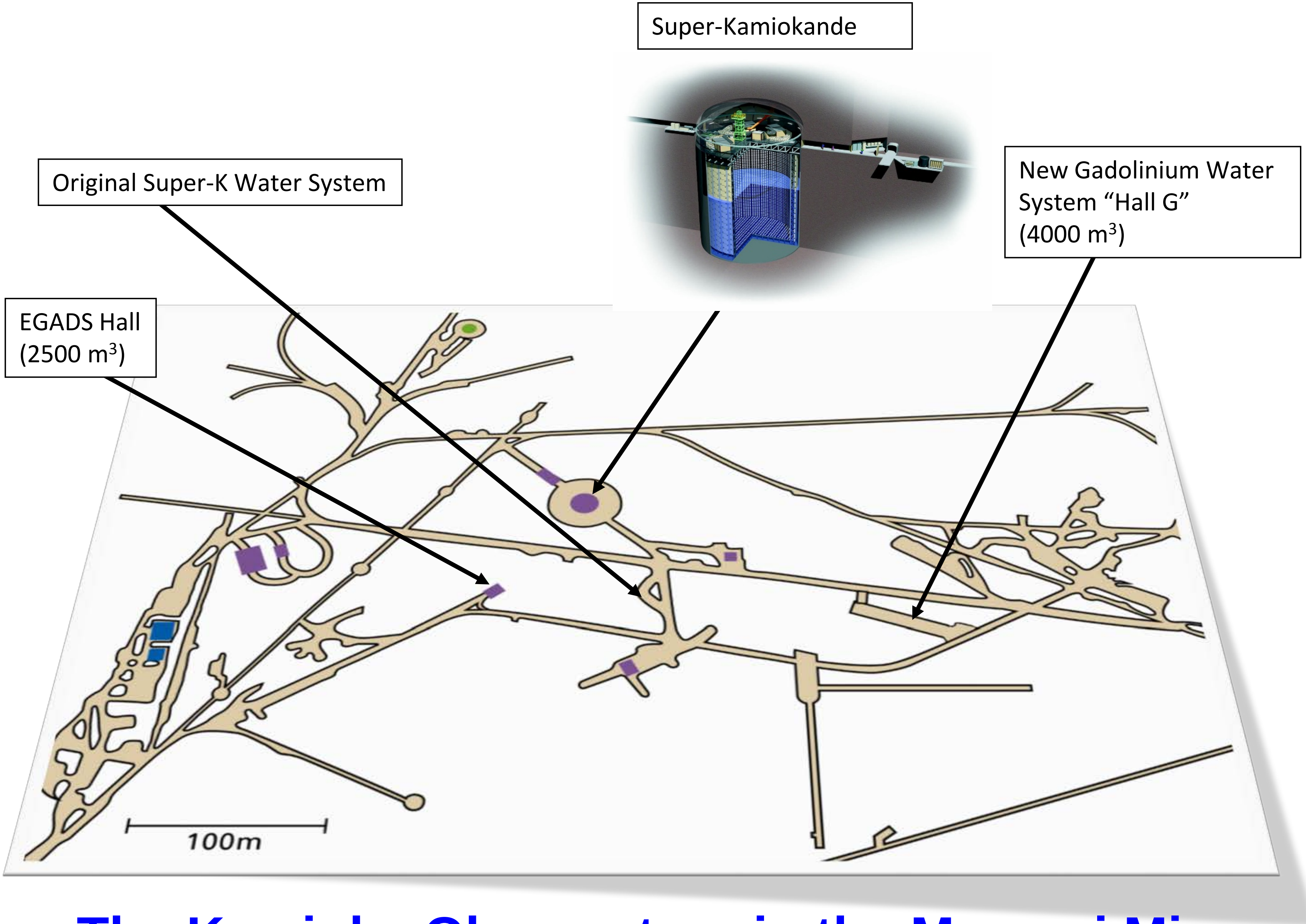
June 27, 2015: The Super-Kamiokande Collaboration approved the addition of gadolinium to the detector, pending discussions with T2K.

January 30, 2016: The T2K Collaboration approved addition of gadolinium to Super-Kamiokande, with the precise timing to be jointly determined based on the needs of both projects.



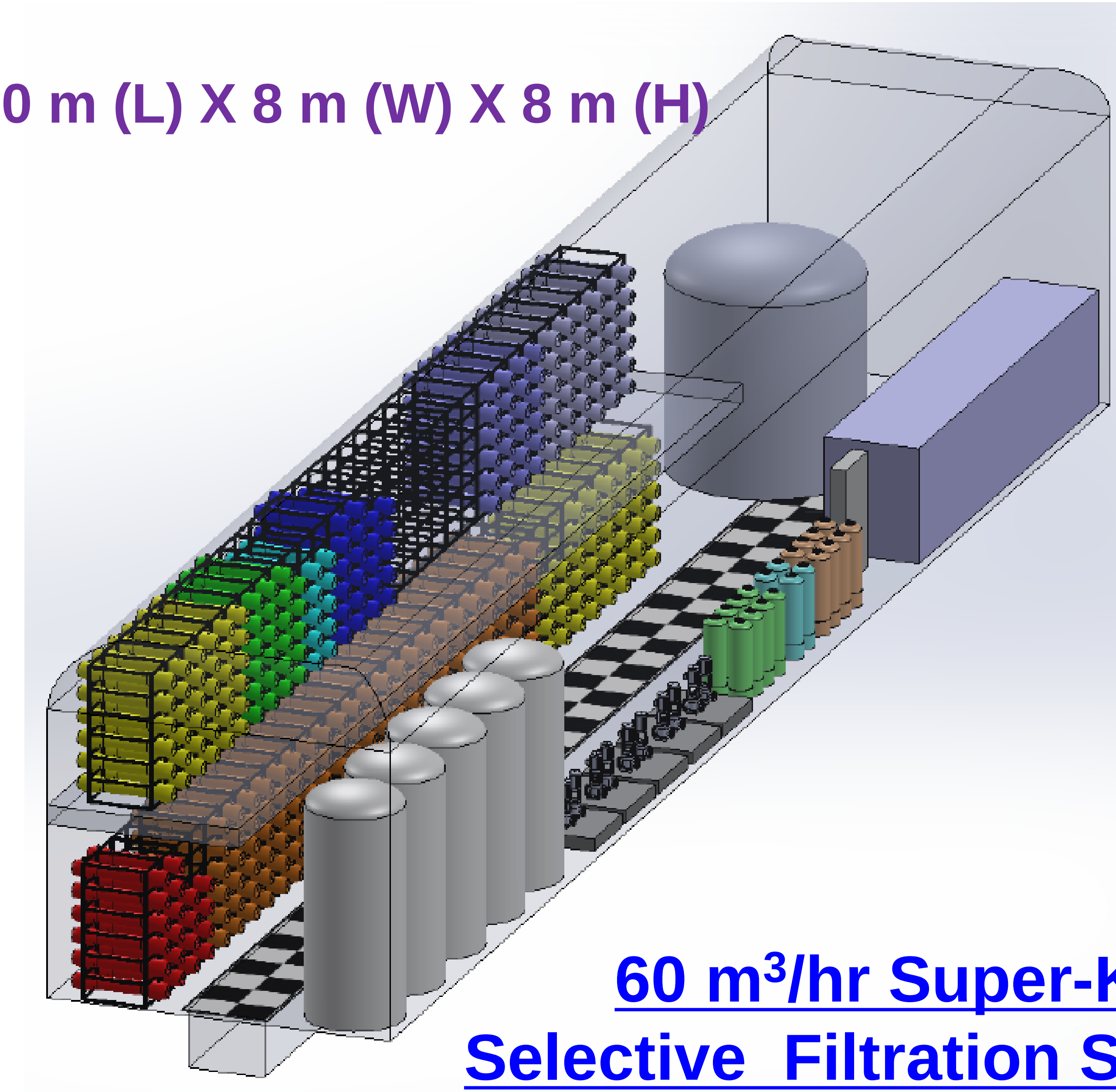
July 26, 2017: The official start time of draining the SK tank to prepare for Gd loading is decided to be June 1, 2018.





The Kamioka Observatory in the Mozumi Mine

New Super-K gadolinium water system

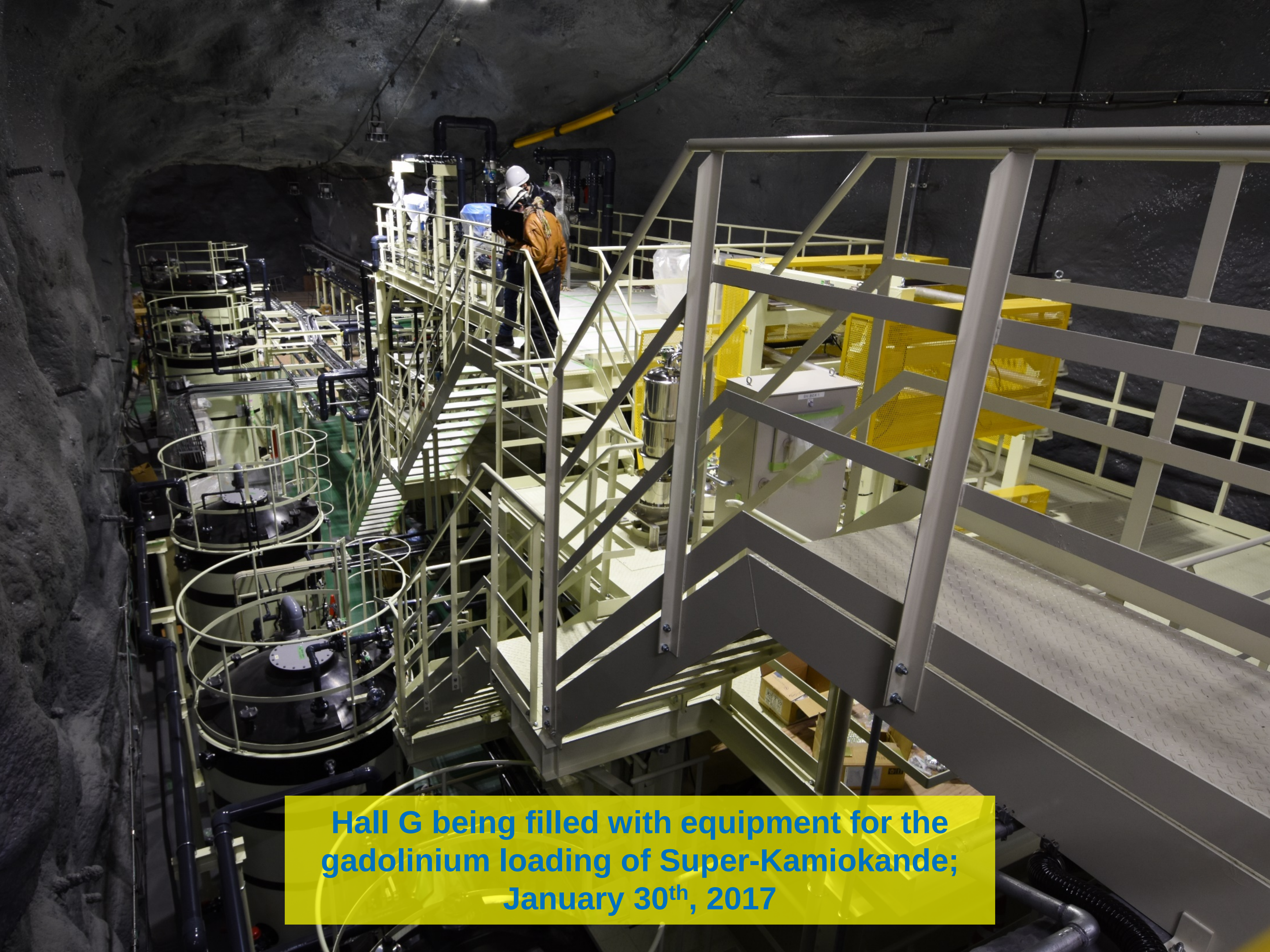


60 m^3/hr Super-K
Selective Filtration System

New gadolinium water system hall ("Hall G");
September 10st, 2015

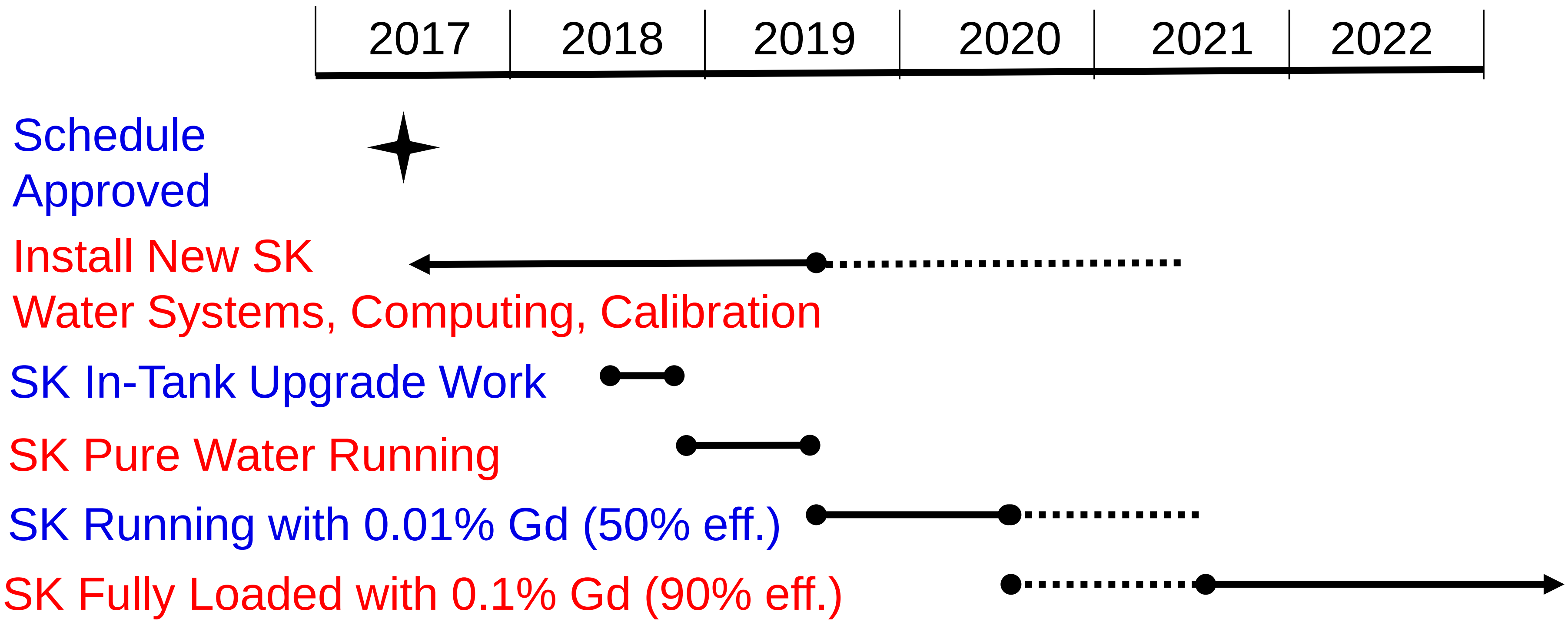

Hall G ready for occupancy;
April 22nd, 2016

Hall G being filled with equipment for the gadolinium loading of Super-Kamiokande; November 10th, 2016



Hall G being filled with equipment for the gadolinium loading of Super-Kamiokande; January 30th, 2017

Timeline for adding Gd to Super-K:



Oh, and one more thing…
EGADS lives on as a
dedicated, Gd-loaded
SN detector

~90,000 ν events
@ Betelgeuse

~40 ν events
@ G.C.

Our target: send out
announcement
within ***<u>one second</u>***
of the SN neutrino
burst's arrival in EGADS!