World-wide Gadolinium-loaded Water

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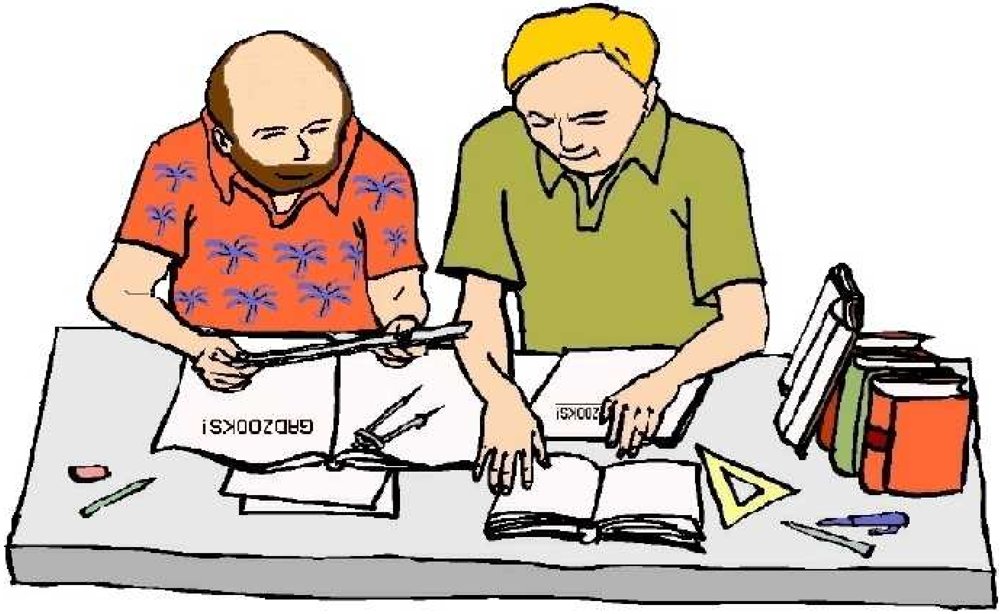
NNN15 Satellite WC Meeting

Stony Brook, NY October 27, 2015



A decade ago theorist John Beacom and I wrote the original GADZOOKS!

(Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande, Super!) paper.

It proposed loading big WC detectors, specifically Super-K, with water soluble gadolinium, and evaluated the physics potential and backgrounds of a giant antineutrino detector.

[Beacom and Vagins, *Phys. Rev. Lett.*, **93**:171101, 2004]
(237 citations → one every 17 days for eleven years)

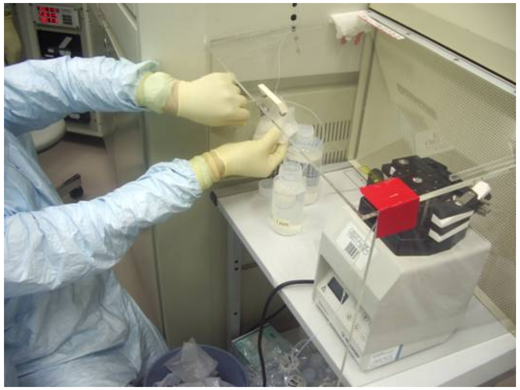
Now, Beacom and I never wanted to merely propose a new technique – we wanted to make it work!

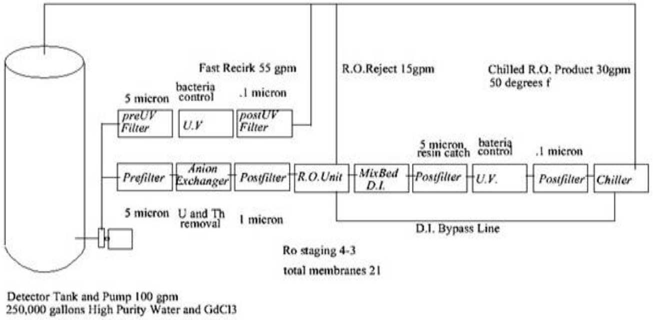
[Snowbird photo by A. Kusenko]

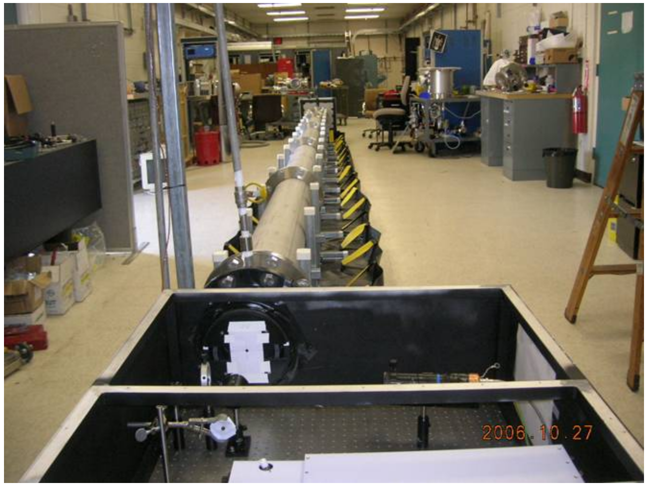
Suggesting a major modification of one of the world's leading neutrino detectors was indeed not the easiest route.

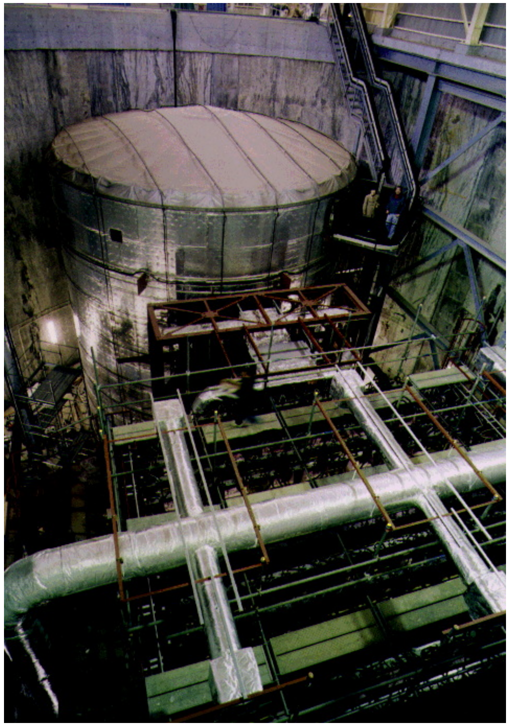
Rather inadvertently, this turned into a working example of shared R&D across national boundaries.

Over the last eleven years there have been a large number of Gd-related R&D studies carried out in the US, Japan, and Spain:









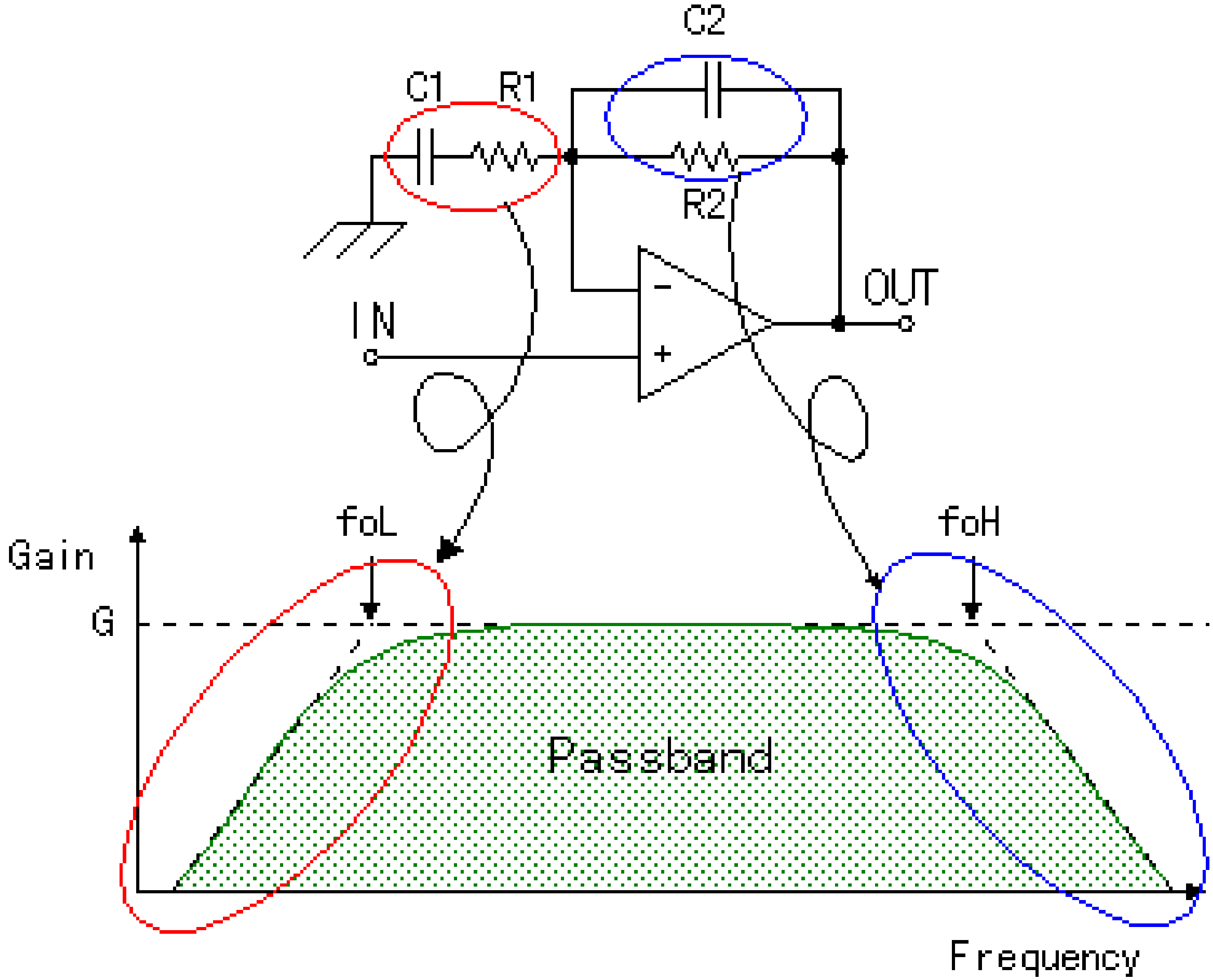
To make gadolinium-loading work, we have to:

Dissolve gadolinium sulfate ($Gd_2(SO_4)_3$) in water
→ Easy and fast (pH control/use octahydrate form)

Remove the gadolinium efficiently and completely when desired
→ Also easy and fast (pH control/DI resin)

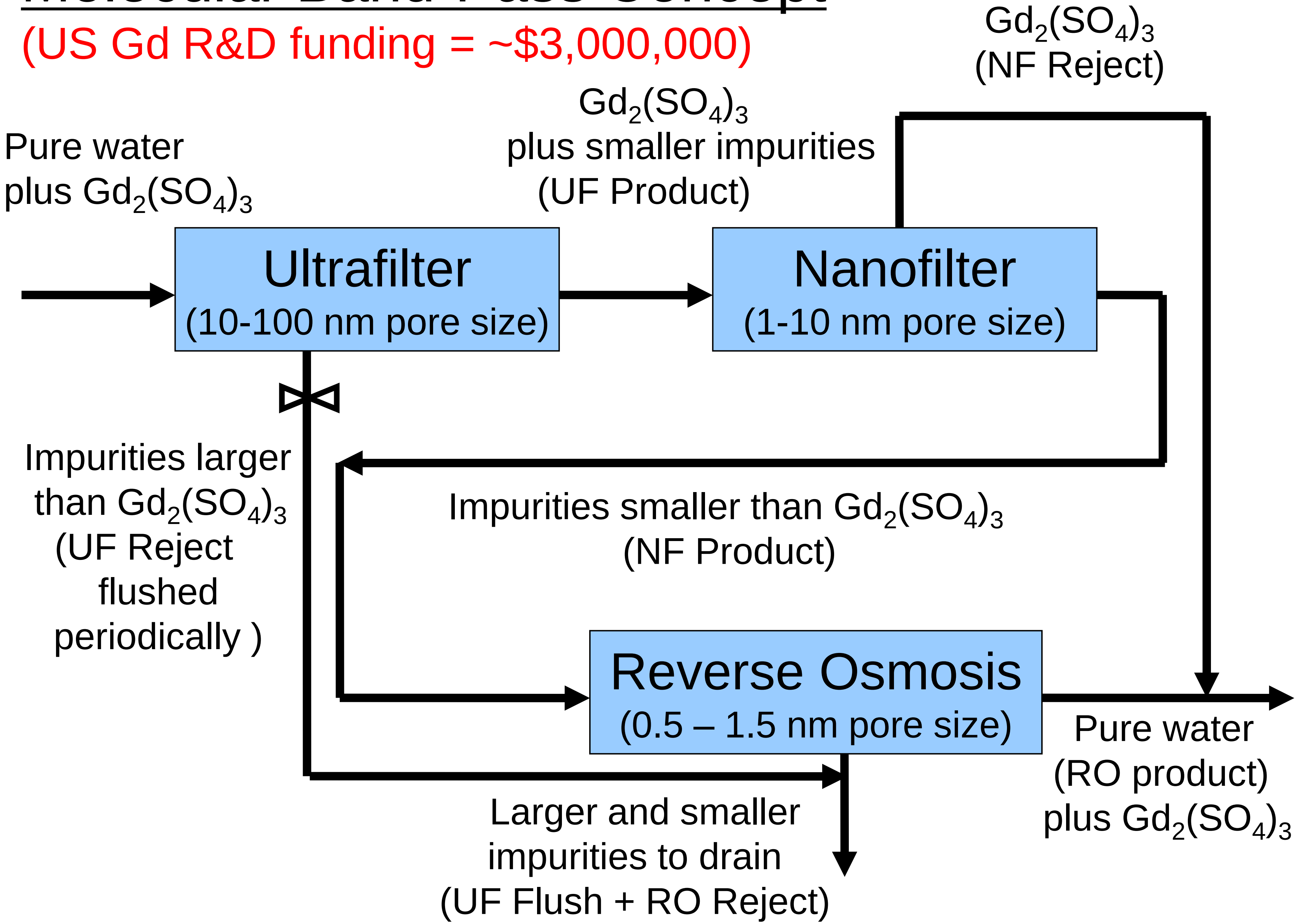
Keep pure water pure yet retain gadolinium sulfate in solution
→ Originally the tricky part, but after years
of hardware work my "molecular band-pass"
selective filtration systems are now operational
(0.2 tons/hr in US since 2007)
(5 tons/hr in Japan since 2010)

Electrical Band-Pass Filter

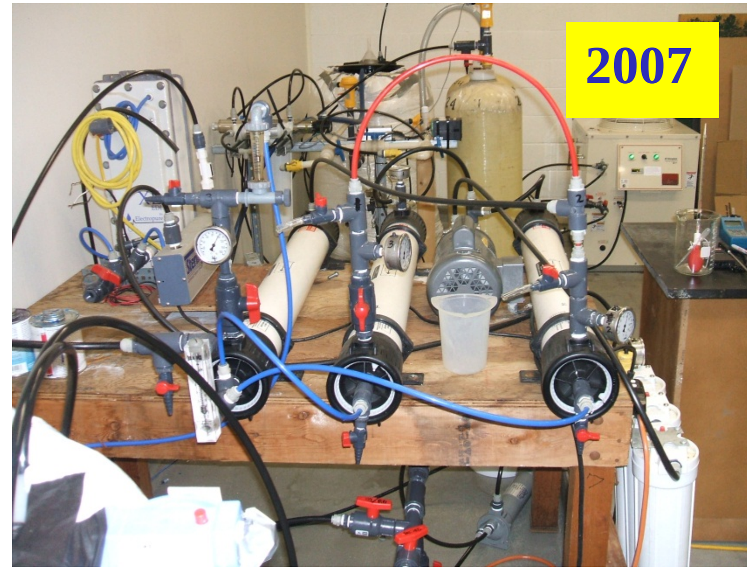


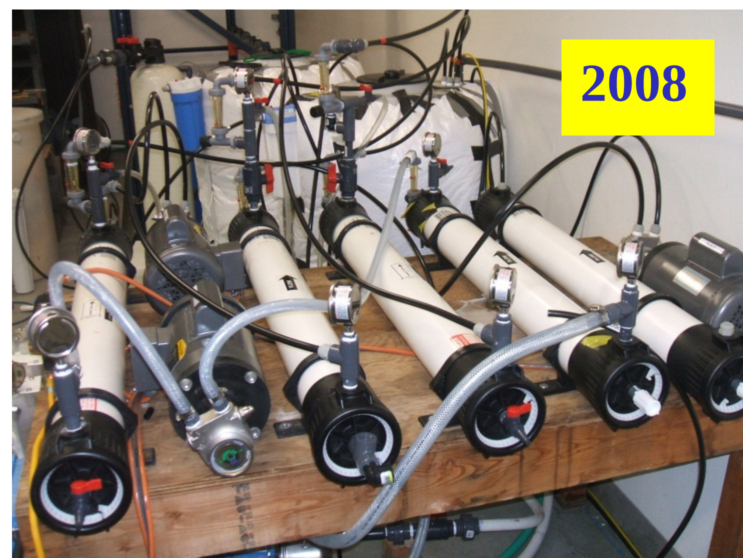
Molecular Band-Pass Concept

(US Gd R&D funding = ~$3,000,000)



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





Prototype Selective Filtration Setup @ UCI

Membrane Pre-Flush

Nanofilter #1

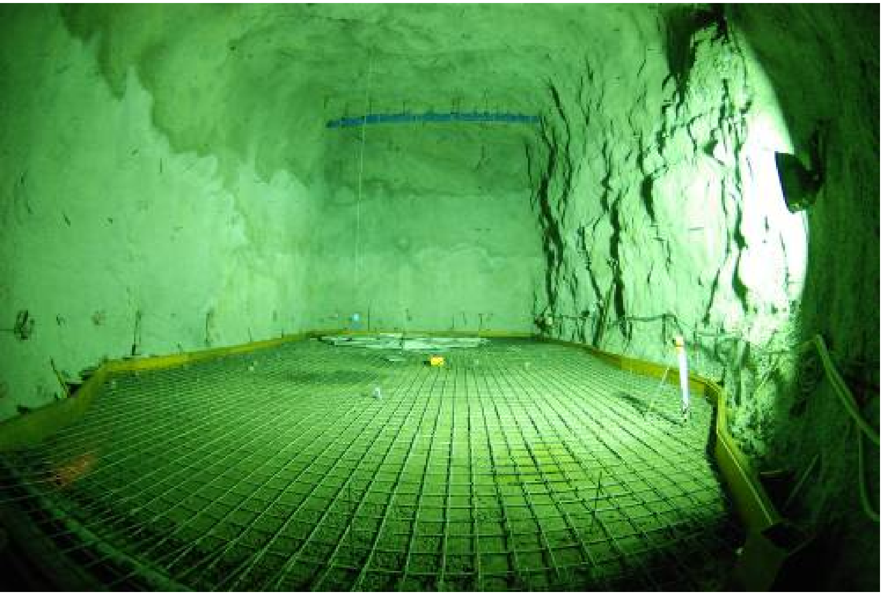
Nanofilter #2

Reverse Osmosis

Ultrafilter

Hall E and EGADS in Japan (Japan Gd R&D funding = ~$7,000,000)

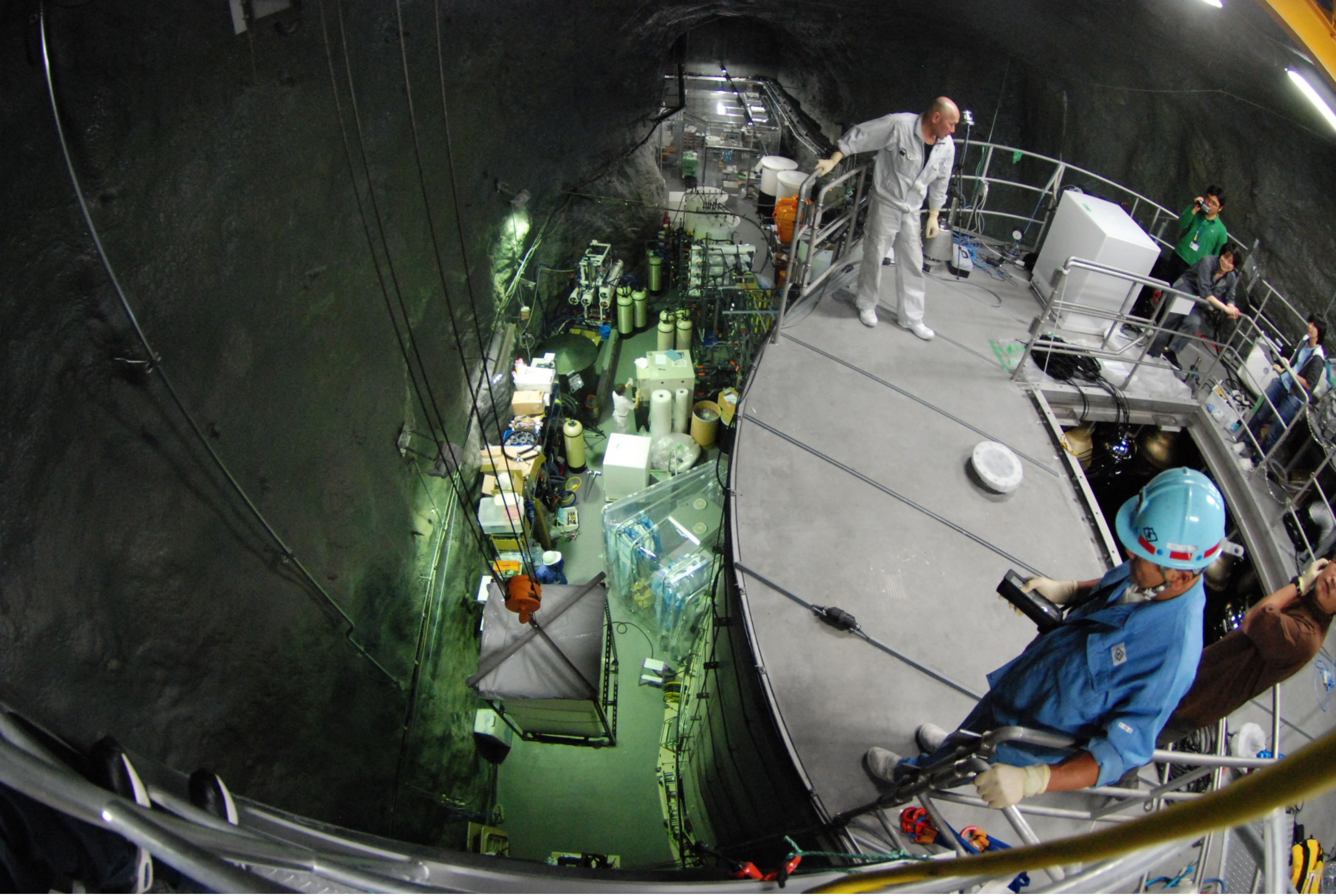
12/2009



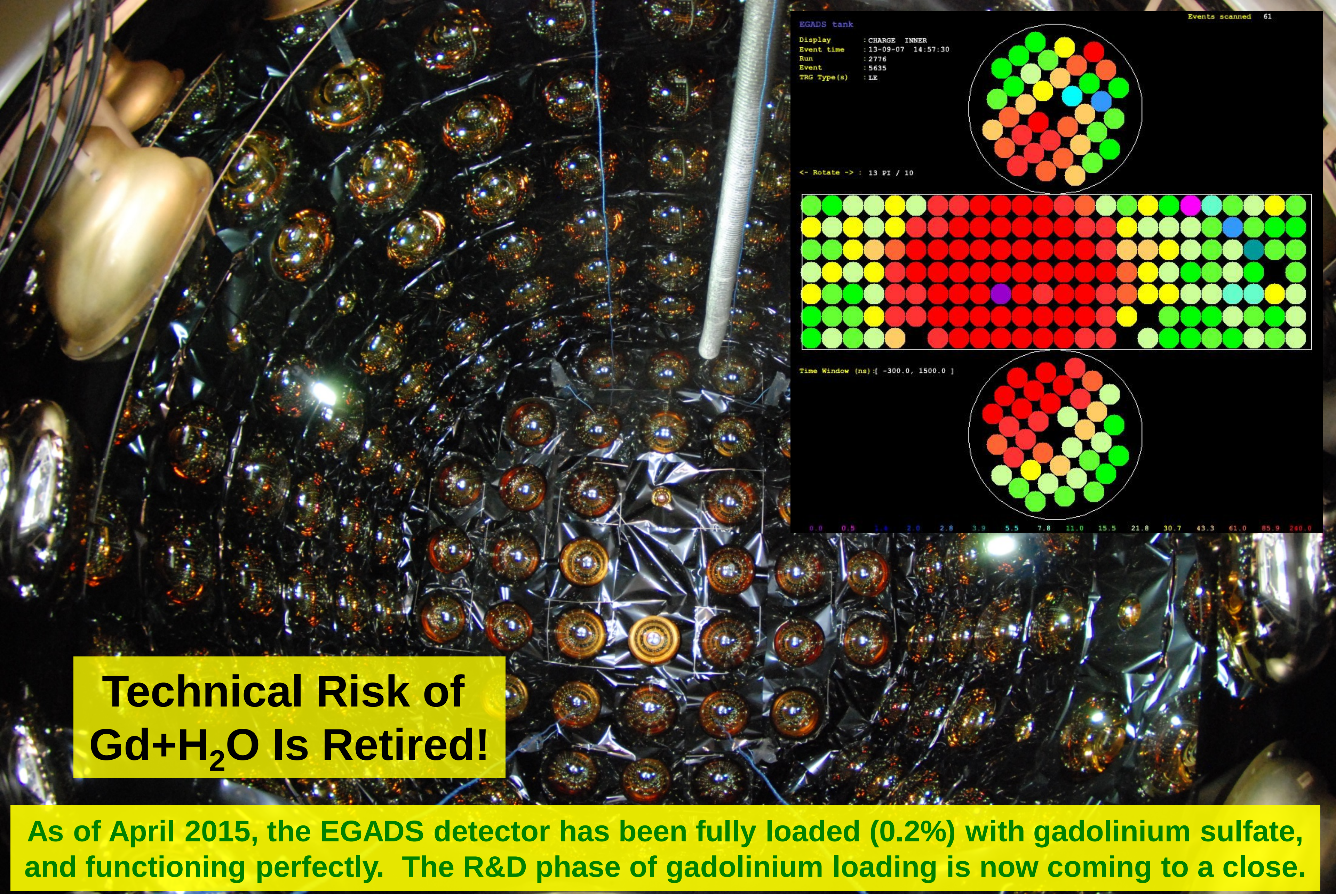
2/2010

6/2010

12/2010



EGADS PMT installation; August 2013

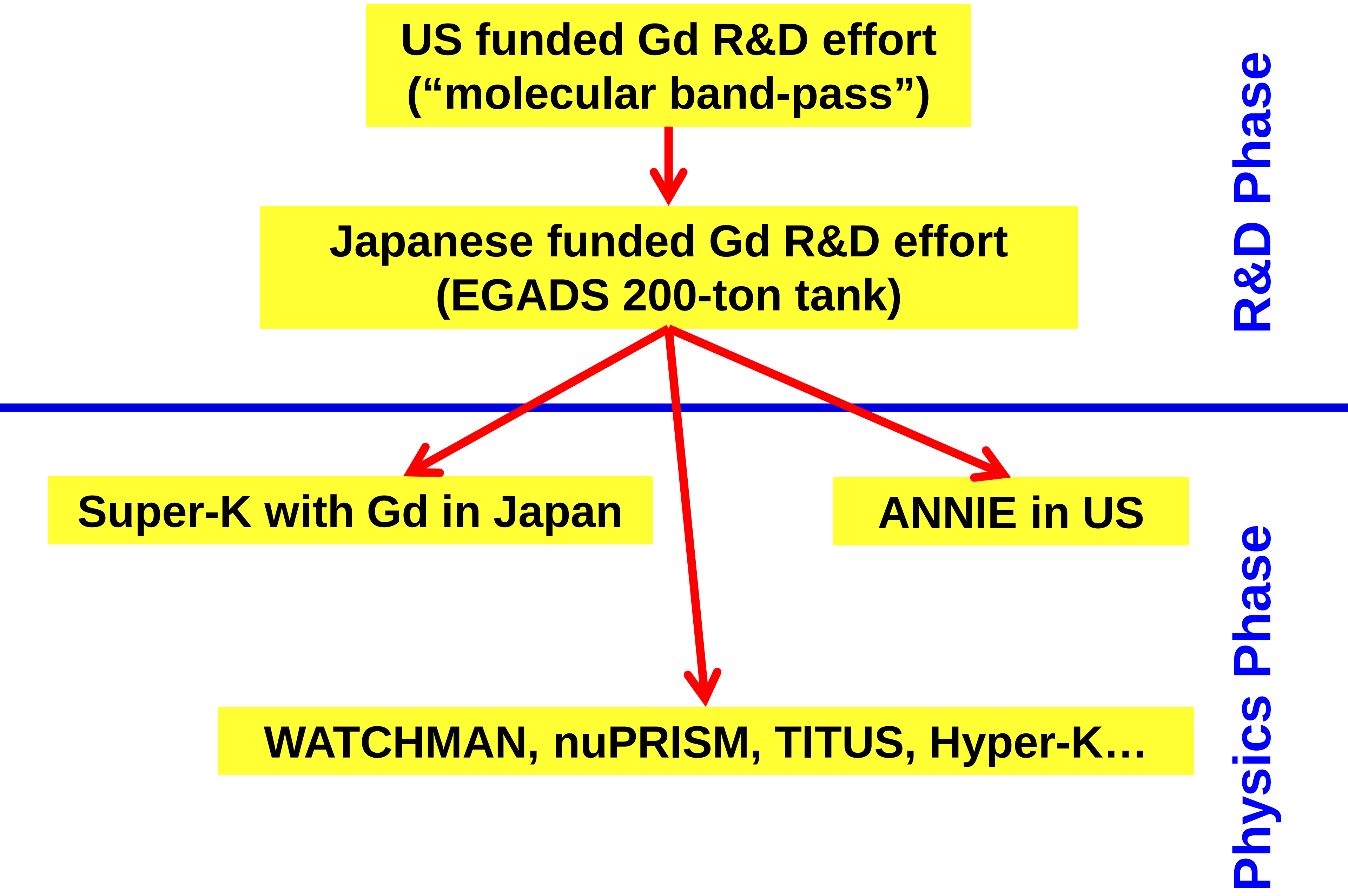


Technical Risk of $Gd+H_2O$ Is Retired!

As of April 2015, the EGADS detector has been fully loaded (0.2%) with gadolinium sulfate, and functioning perfectly. The R&D phase of gadolinium loading is now coming to a close.

Looking Down Into the 200-ton EGADS Detector; August 2013

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


US funded Gd R&D effort
("molecular band-pass")
Japanese funded Gd R&D effort
(EGADS 200-ton tank)
R&D Phase
Super-K with Gd in Japan
ANNIE in US
WATCHMAN, nuPRISM, TITUS, Hyper-K…
Physics Phase

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August 31, 2015

Dear ANNIE Spokespeople,

I am writing to formalize a contribution in kind to be made to the ANNIE project.

After first proposing – with theorist co-author John Beacom – the use of water soluble gadolinium compounds to greatly enhance the physics reach of water Cherenkov detectors, I have spent the past twelve years developing and proving out the needed equipment. This has taken place in the US at the University of California, Irvine (where I also hold an Adjunct Professor position) and at the University of Tokyo, culminating in the construction of a multi-million dollar, dedicated large-scale R&D test facility in Japan known as EGADS: Evaluating Gadolinium's Action on Detector Systems. It consists of a 200-ton scale model of Super-Kamiokande, my advanced-technology water filtration equipment, and monitoring devices of various sorts. I am the PI of this project, which has now conclusively demonstrated the technologies required for the gadolinium-loaded water technique upon which ANNIE relies for neutron identification.

I hereby commit Kavli IPMU and the University of Tokyo to supplying 50 kilograms of high purity (99.99% REO/TREO) gadolinium sulfate octahydrate, $Gd_2(SO_4)_3*8H_2O$, to the ANNIE Collaboration. This quantity of rare-earth salt, sufficient for one full loading (at 0.2% by mass) of ANNIE, as well as some additional testing and trials, will be shipped from Japan to Fermilab without cost to the Collaboration.

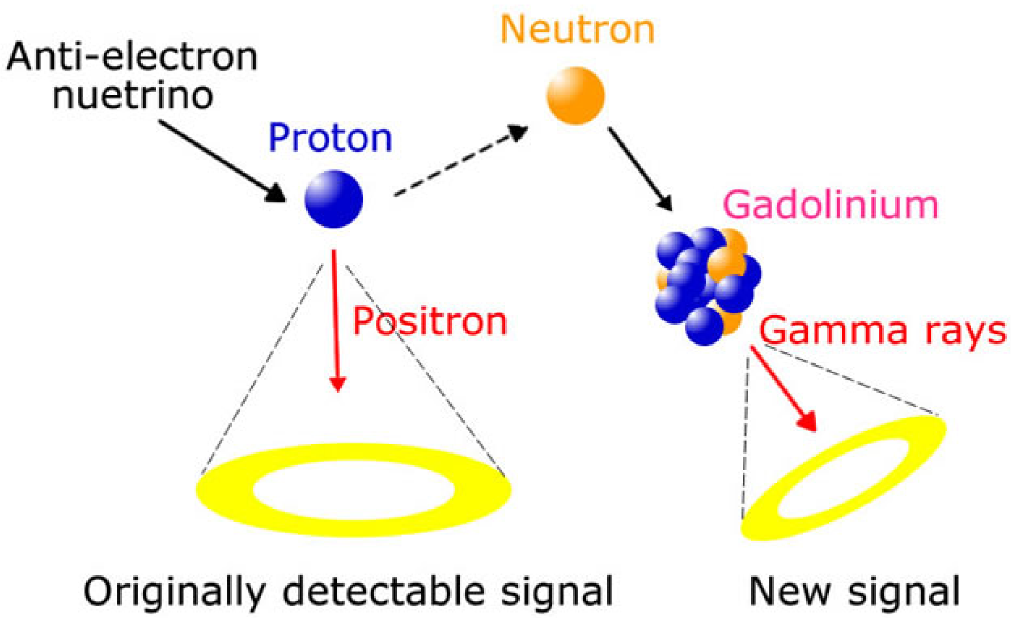
This in-kind contribution to the project from the University of Tokyo is valued at approximately $20,000.

Sincerely,
Professor Mark Vagins
Kavli IPMU
University of Tokyo

東京大学
THE UNIVERSITY OF TOKYO

So, the R&D phase for Gd-loaded WC detectors is just about finished. It only took a decade or so!

What do we need done now, other than building really cool, next-generation detectors?



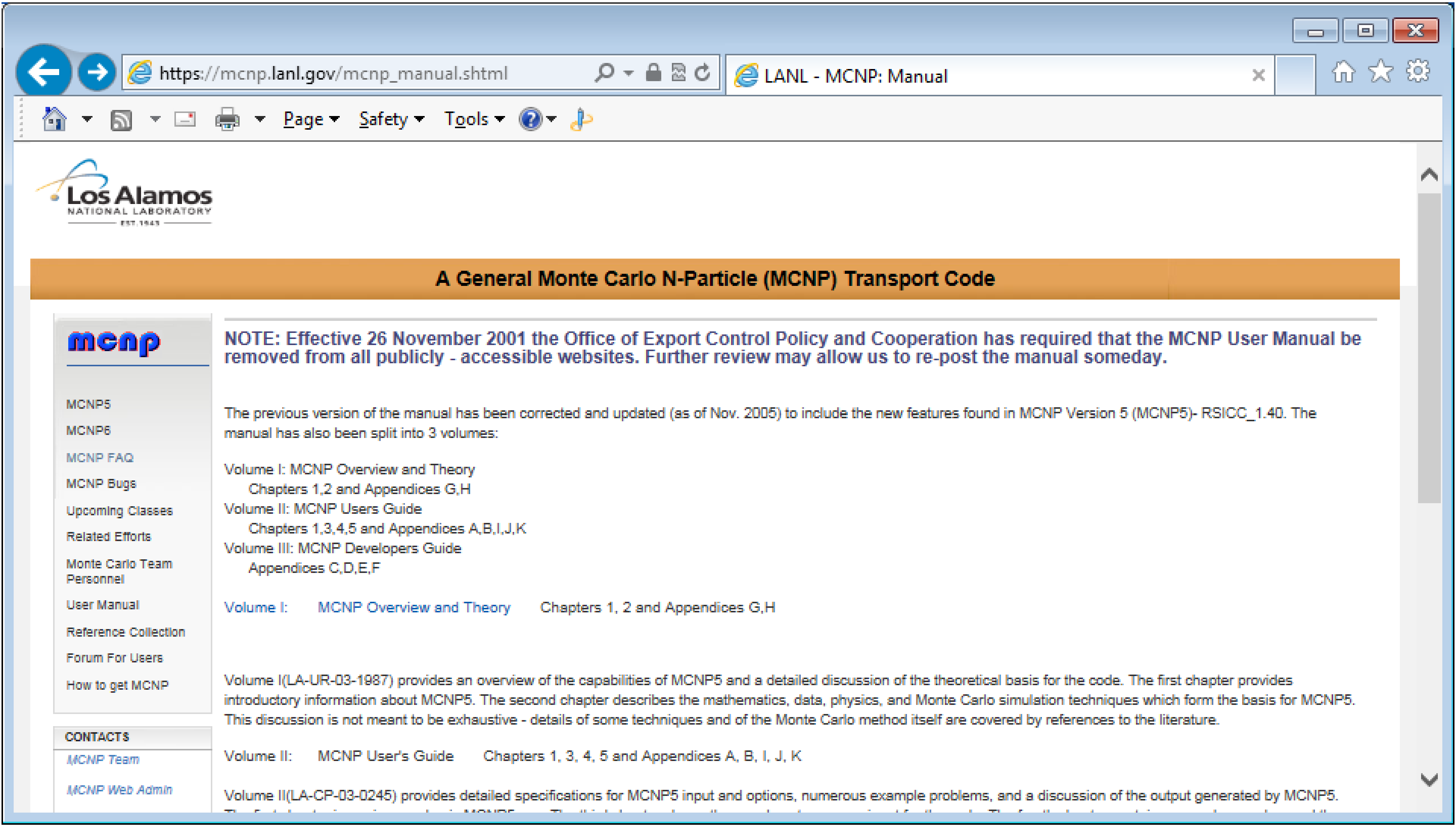
Well, it turns out that properly simulating the ~8.0 MeV gamma cascade following a neutron capture on Gd is tricky… on average there are 3.9 gammas emitted per neutron.

In EGADS we have been using GEANT4 + GLG4Sim, but GLG4Sim was designed for scintillator detectors and it does not get the energy quite right in water.

Simulating Gd in water is different than Gd in scintillator, because gammas much less than 1 MeV are invisible in WC detectors, since they cannot Compton scatter off electrons and make them sufficiently relativistic to generate Cherenkov light.. Therefore, correlations between gammas are critical.

The gold standard is a program produced (and controlled by) Los Alamos and Oak Ridge National Laboratories, called Monte Carlo N-Particle code (MCNP). It was created in 1957 – and continually updated since – to facilitate, among other things, “nuclear criticality safety”.

MCNP’s distribution has effectively been restricted to US citizens, making international collaboration challenging..



https://mcnp.lanl.gov/mcnp_manual.shtml

LANL - MCNP: Manual

Page Safety Tools

Los Alamos NATIONAL LABORATORY EST. 1943

A General Monte Carlo N-Particle (MCNP) Transport Code

mcnp

MCNP5
MCNP6
MCNP FAQ
MCNP Bugs
Upcoming Classes
Related Efforts
Monte Carlo Team Personnel
User Manual
Reference Collection
Forum For Users
How to get MCNP

CONTACTS
MCNP Team
MCNP Web Admin

NOTE: Effective 26 November 2001 the Office of Export Control Policy and Cooperation has required that the MCNP User Manual be removed from all publicly - accessible websites. Further review may allow us to re-post the manual someday.

The previous version of the manual has been corrected and updated (as of Nov. 2005) to include the new features found in MCNP Version 5 (MCNP5)- RSICC_1.40. The manual has also been split into 3 volumes:

Volume I: MCNP Overview and Theory
 Chapters 1,2 and Appendices G,H
Volume II: MCNP Users Guide
 Chapters 1,3,4,5 and Appendices A,B,I,J,K
Volume III: MCNP Developers Guide
 Appendices C,D,E,F

Volume I: MCNP Overview and Theory Chapters 1, 2 and Appendices G,H

Volume I(LA-UR-03-1987) provides an overview of the capabilities of MCNP5 and a detailed discussion of the theoretical basis for the code. The first chapter provides introductory information about MCNP5. The second chapter describes the mathematics, data, physics, and Monte Carlo simulation techniques which form the basis for MCNP5. This discussion is not meant to be exhaustive - details of some techniques and of the Monte Carlo method itself are covered by references to the literature.

Volume II: MCNP User's Guide Chapters 1, 3, 4, 5 and Appendices A, B, I, J, K

Volume II(LA-CP-03-0245) provides detailed specifications for MCNP5 input and options, numerous example problems, and a discussion of the output generated by MCNP5.

Oy… it's (almost?) like they don't want anyone to use it!

So this is a topic with which we could <u>definitely</u> use help.