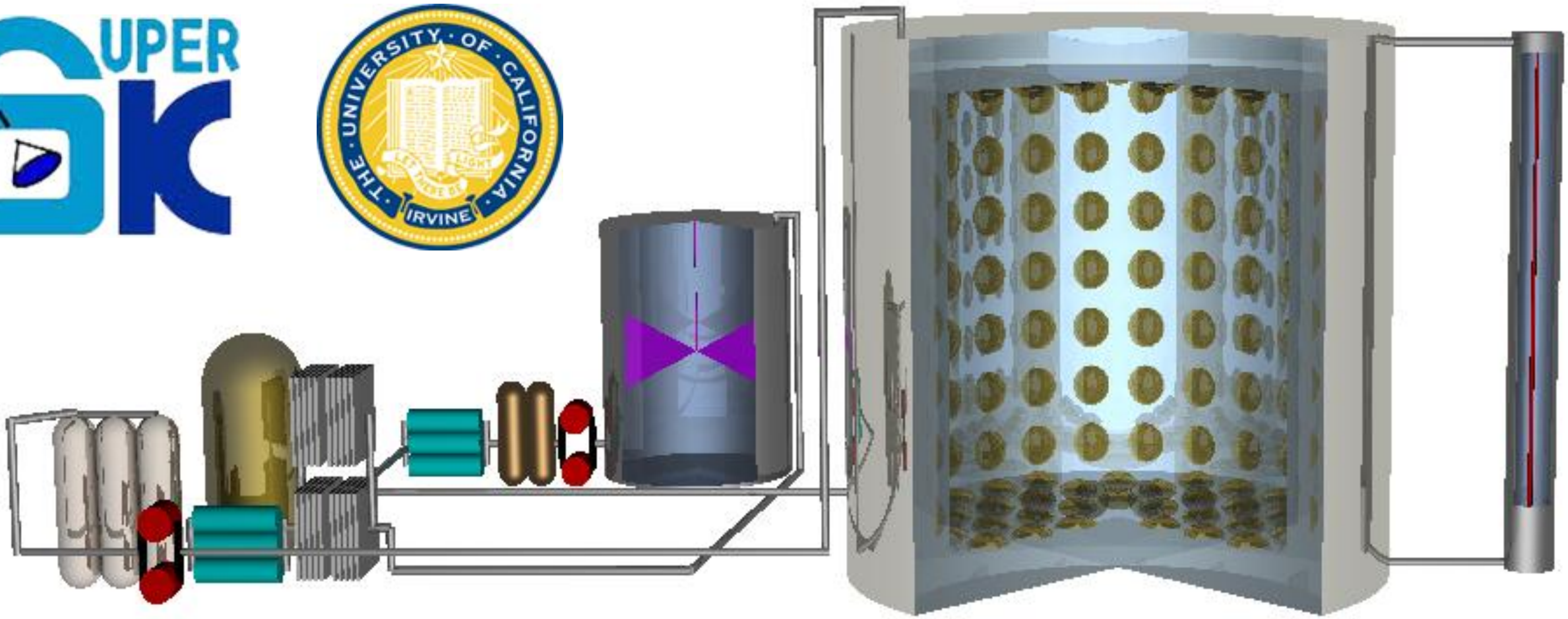
R&D For A Gadolinium Doped Water Cherenkov Detector



Andrew Renshaw for the
Super-Kamiokande Collaboration

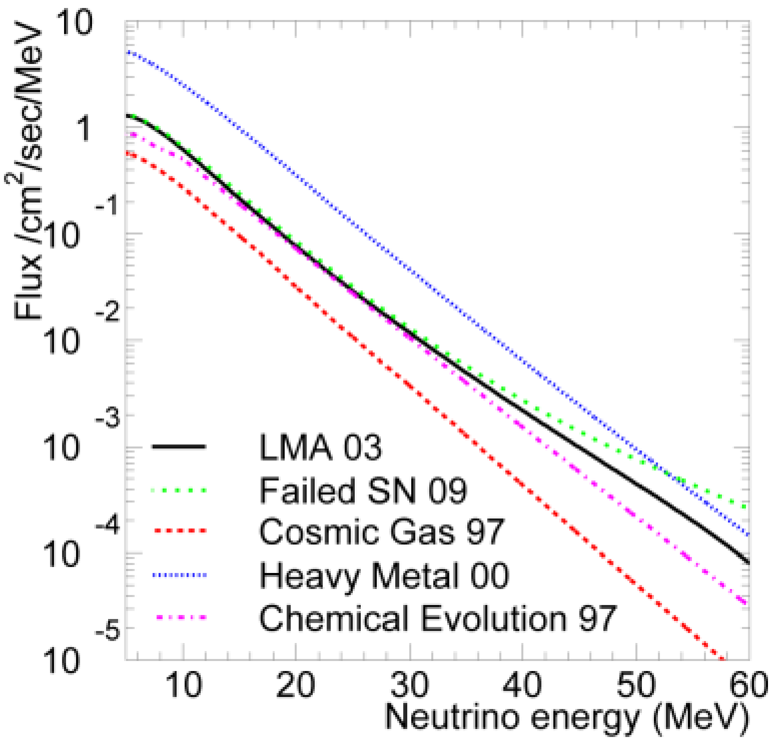
TIPP 2011: Monday June 13th, 2011

Low Energy Physics With A Water Cherenkov Detector

- Electron-neutrino elastic scattering used in solar analysis to discriminate signal and background by directionality
- Anti-neutrinos seen via inverse beta decay (same Cherenkov sig. as above but no directionality)
- Searching for singles events, at energies where radioactive isotopes and spallation products can dominate, searches are limited by background

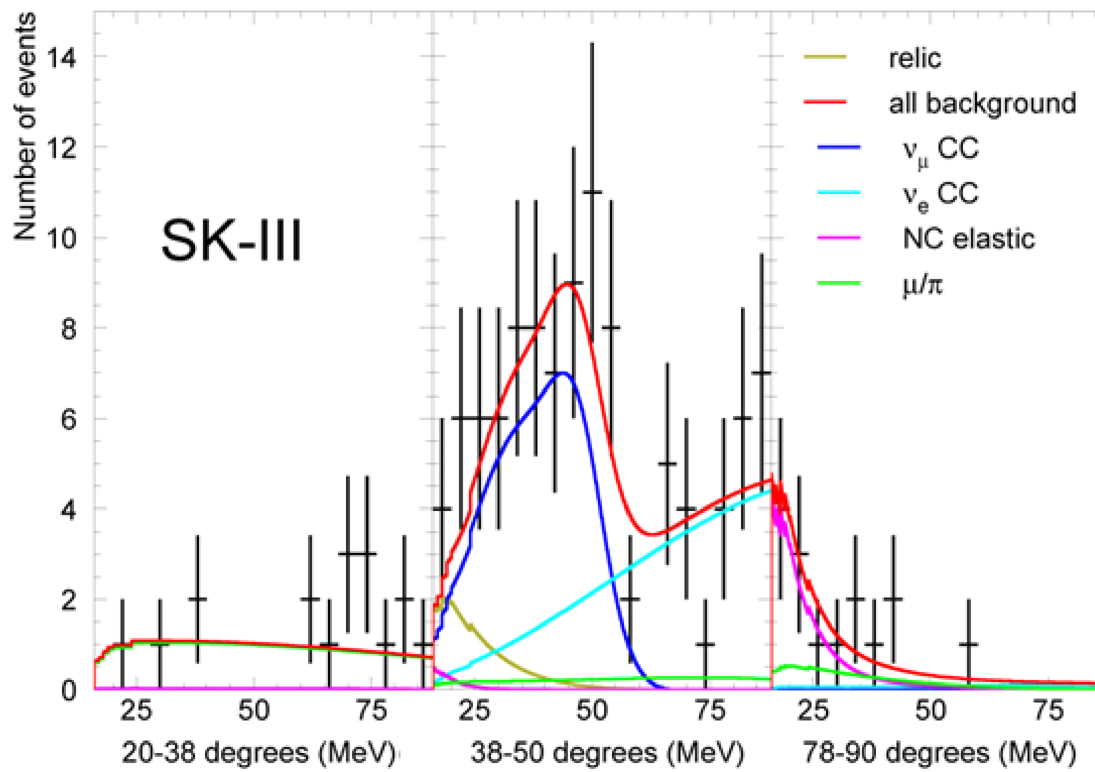
Supernova Relic Neutrino(SRN) Search at Super Kamiokande(SK)

Examples of theoretical SRN spectra



New unbinned maximum likelihood fit

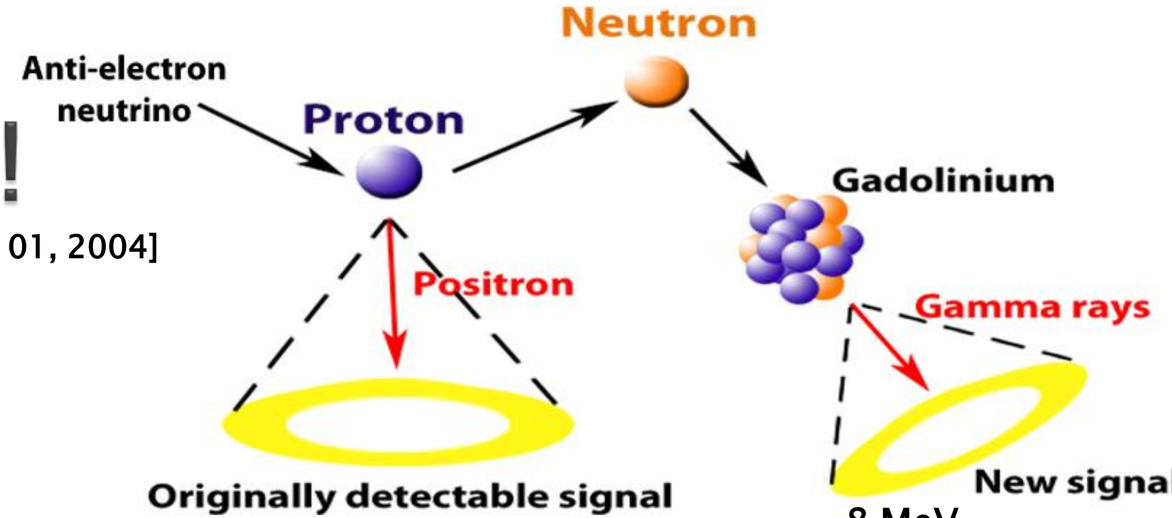
Backgrounds are still dominate, so only best flux limit



We need to “tag” the antineutrinos…

GADZOOKS!

[Beacom and Vagins, Phys. Rev. Lett., 93:171101, 2004]

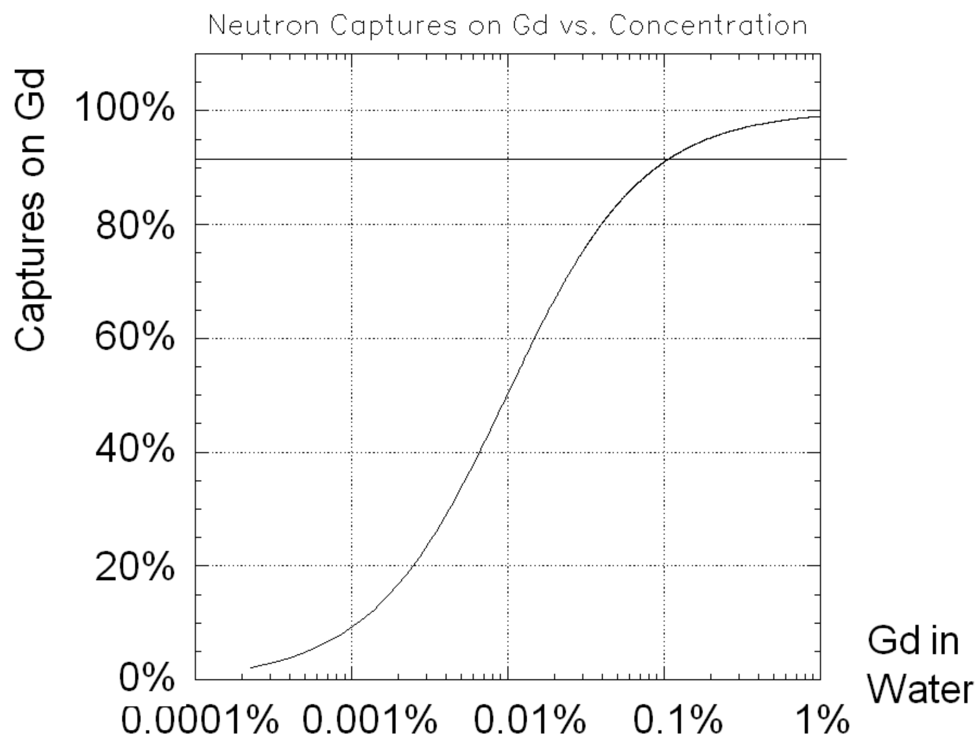


8 MeV cascade, easily seen in SK

With 0.1% Gd Loading

~90% or more of the time

n+Gd→~8MeV γ
ΔT = ~30 μsec
(J.Beacom and M.Vagins)
Phys.Rev.Lett.93:171101, 2004



Gd Inside SK

$\alpha + {}^{9}Be \rightarrow {}^{12}C^{*} + n$ (Am/Be Source)

${}^{12}C^{*} \rightarrow {}^{12}C + \gamma(4.4\ \text{MeV})$

BGO signal (prompt signal (large and long time pulse))

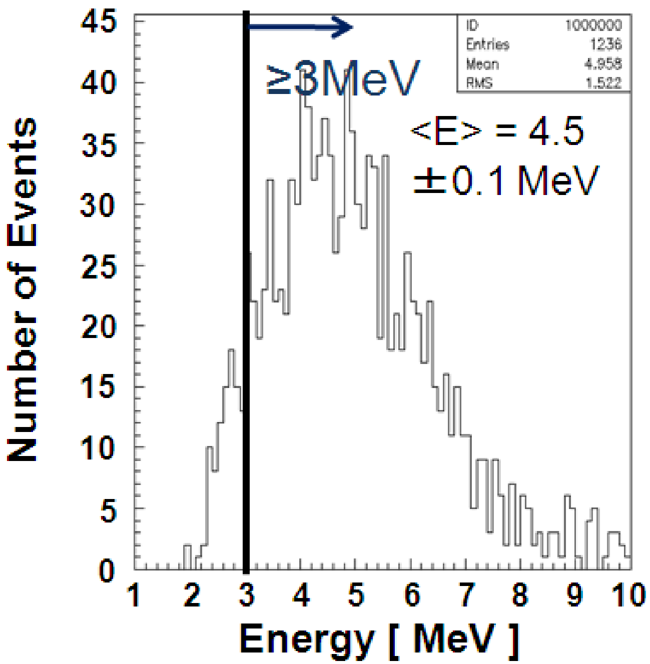
$n+p \rightarrow ...... \rightarrow n + Gd \rightarrow Gd + \gamma$

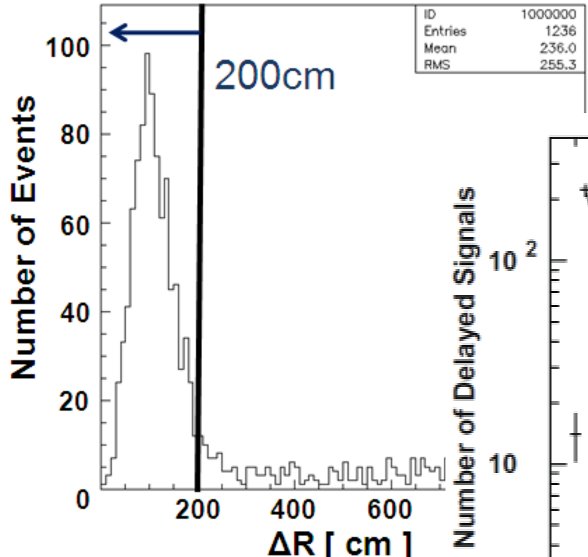
Look for Cherenkov signal (delayed signal)

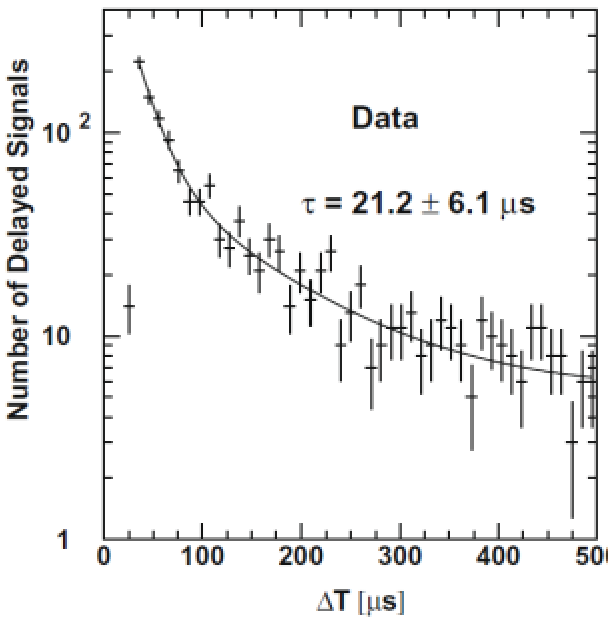
2007: 0.2 % $GdCl_3$ Solution

[SK Collab, Astropart. Phys. 31, 320-328 (2009)]

2010: 0.2% $Gd_2(SO_4)_3$ Solution



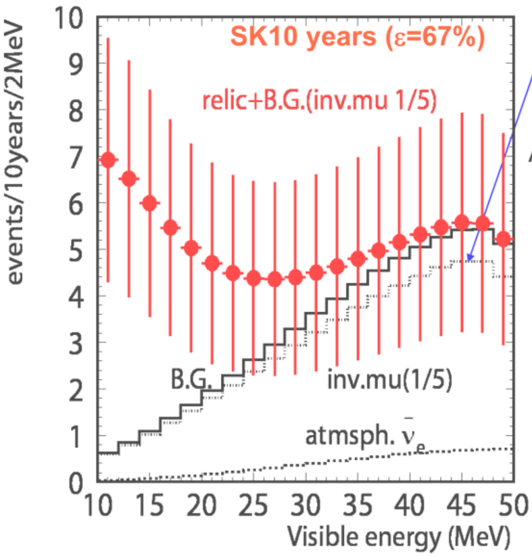




New Signals In SK

Up to 5 SRN events per year

If invisible muon background can be reduced by neutron tagging



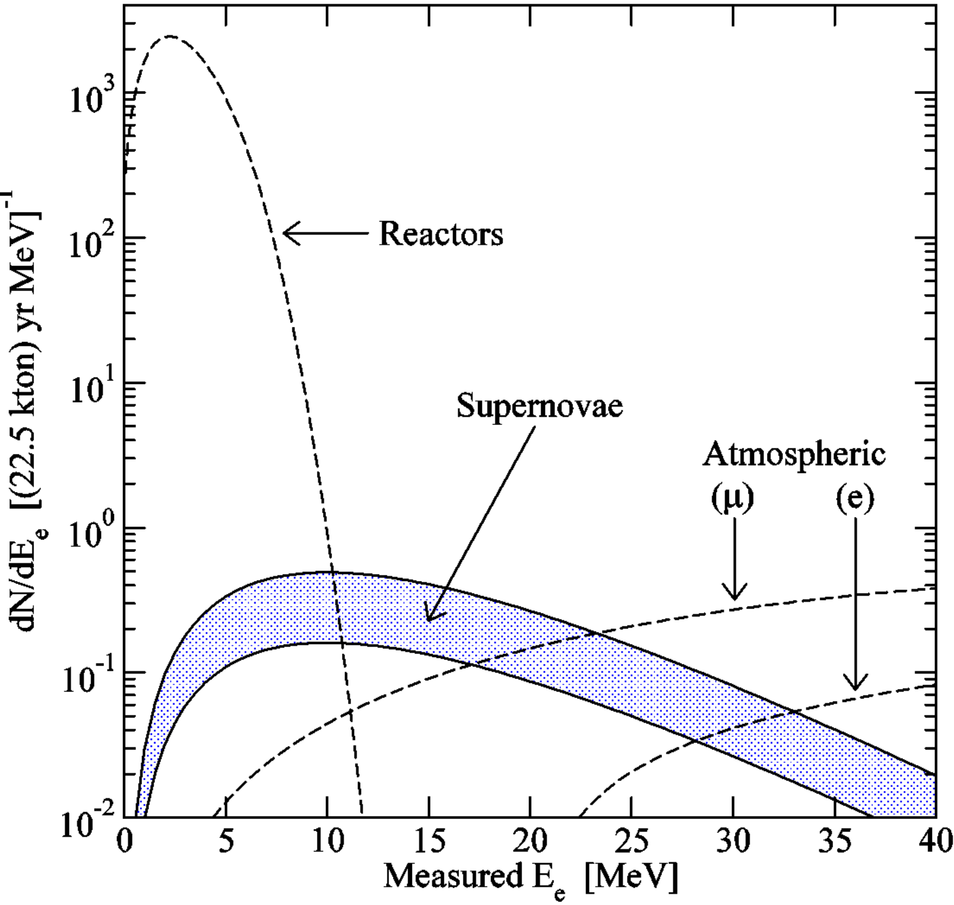
Assuming invisible muon B.G. can be reduced by a factor of 5 by neutron tagging.

Assuming 67% detection efficiency.

By 10 yrs SK data,
Signal: 33, B.G. 27
(E_{vis} =10-30 MeV)

[M. Nakahata, Neutrino 2008]

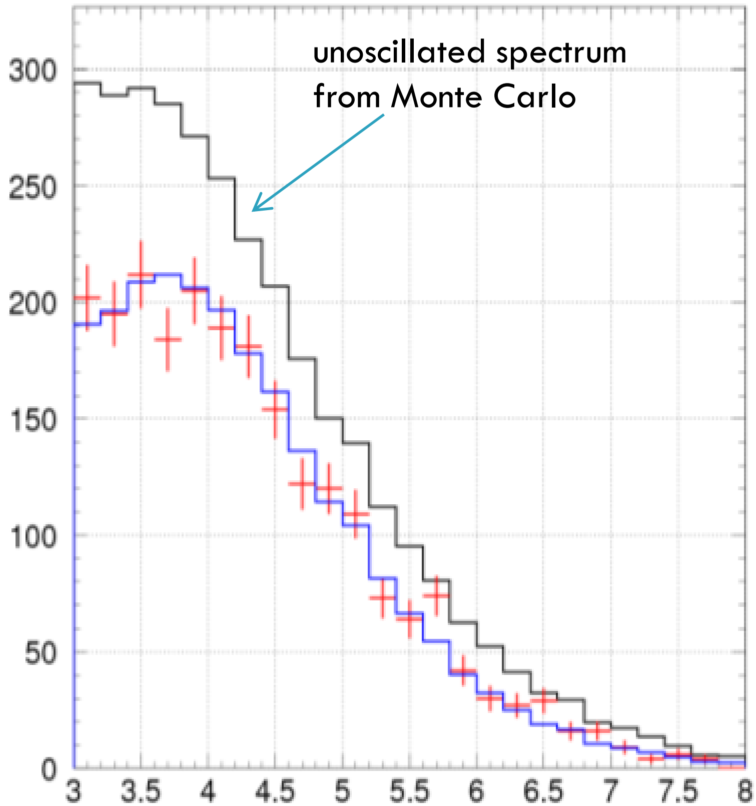
SK coincident signals after adding ~100 tons of soluble Gd



[Beacom and Vagins, Phys. Rev. Lett., 93:171101, 2004]

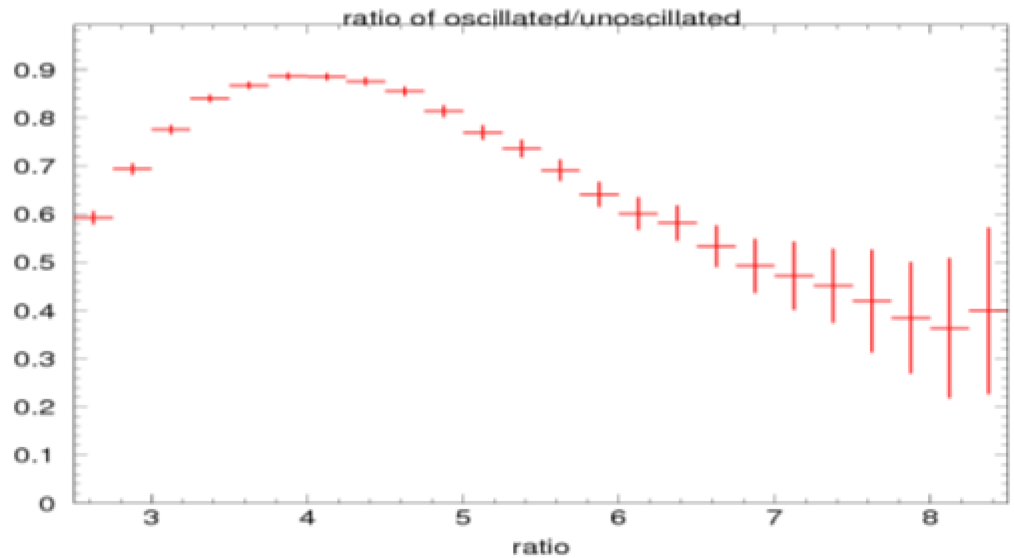
New Signals In SK

~1000 or more reactor neutrino per year



One year MC study assuming Δm^2 = 8E−5 and sin^2(2θ) = .86

Positron spectrum from one year of Monte Carlo oscillated

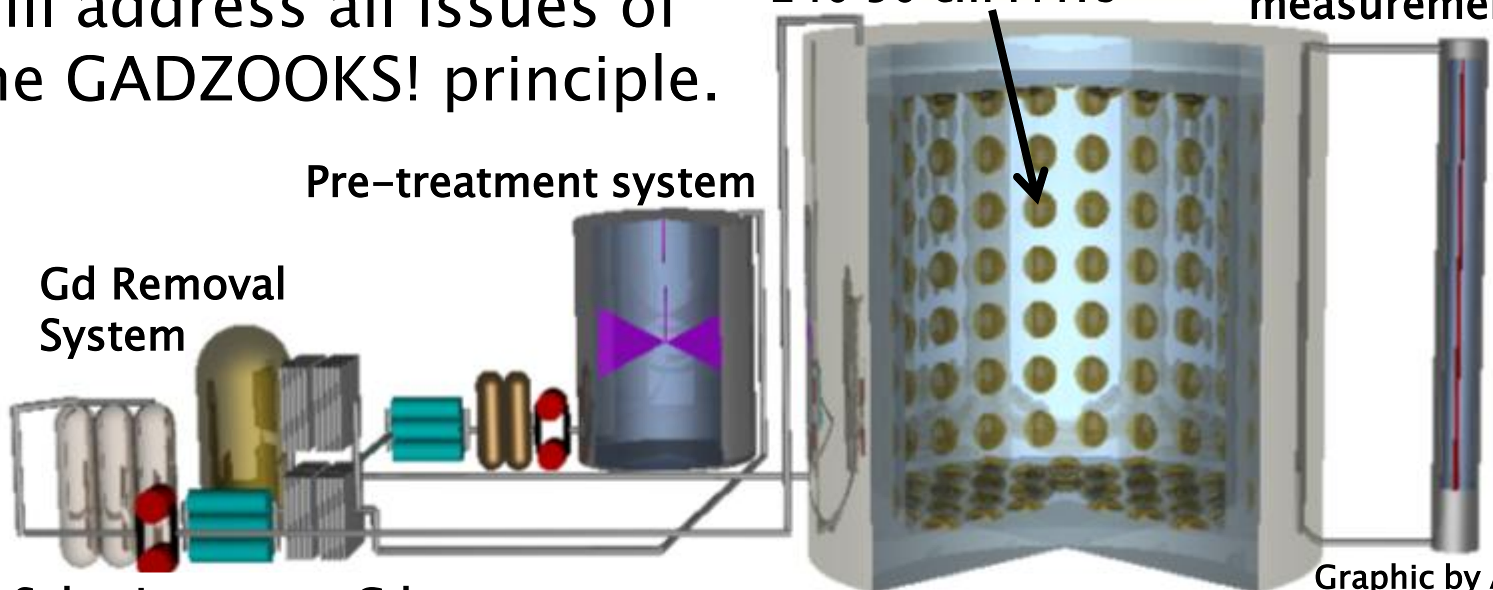


Other Added Benfits

- Ability to identify inverse beta events from a galactic supernova
  - Study remaining reactions
  - ->2x improved pointing precision
  - Potential for very early warning and very late time observations
- Study of the solar electron antineutrino flux
- Better study of hadronic final states in atmospheric/accelerator neutrino events, help identify (anti)neutrino, and also reactions
- Neutrino-neutron elastic scattering will be a significant new neutral-current channel in accelerator studies
- Atmospheric neutrino background reduction for proton decay analysis, and aid in bound-nucleon decay w/ ejected neutron

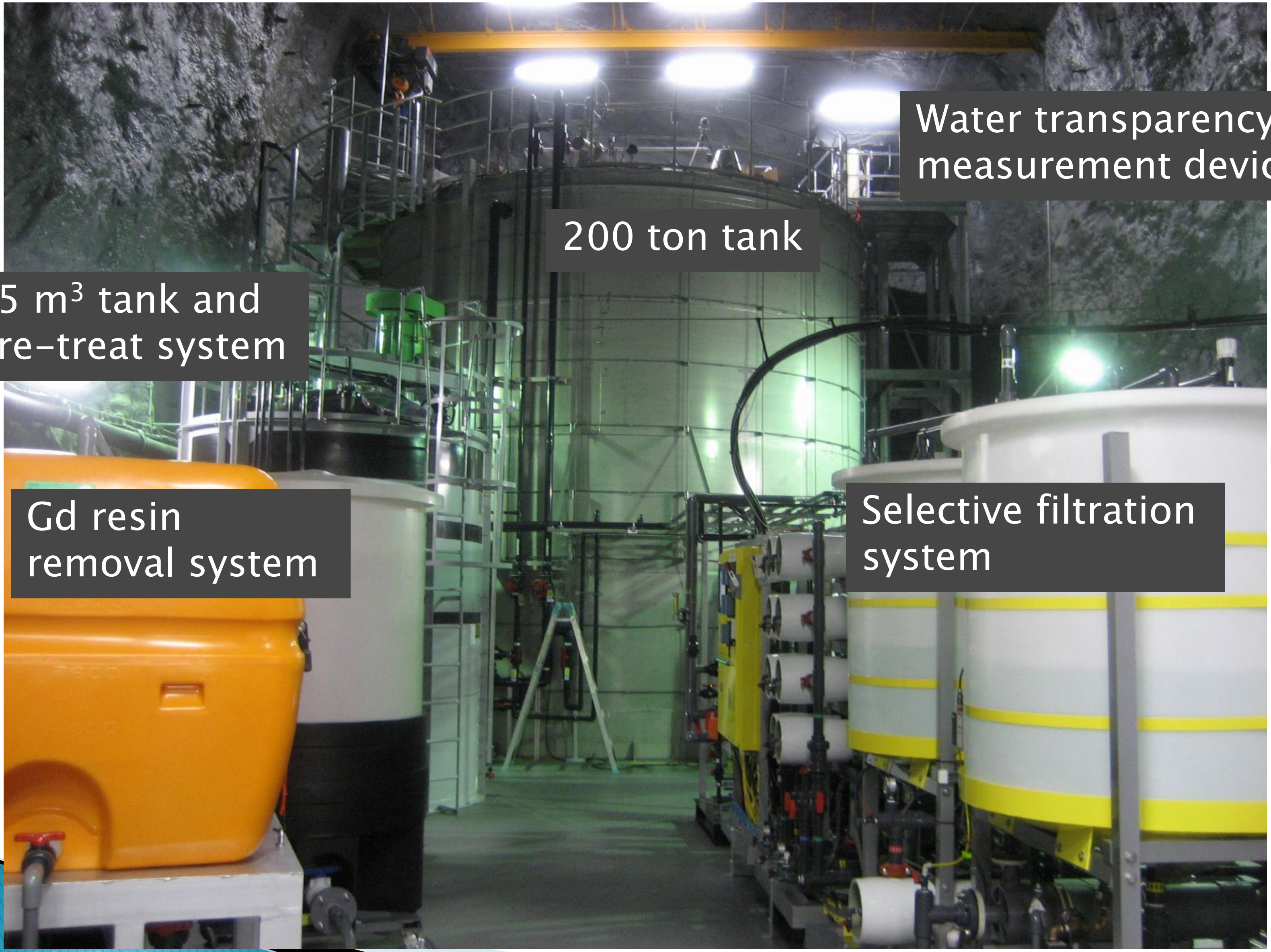
Pushing The Gd Front

- Many studies have been ongoing in both the US and Japan over the last 8 years
- EGADS (Evaluating Gadolinium's Action on Detector Systems)
  - New dedicated, multi-million dollar test facility
  - Kamioka mine (near SK)
  - Will address all issues of the GADZOOKS! principle.



Graphic by A. Kibayashi

A Look In The Lab



Challenges Faced

- Compound to be used
- Introduction and removal
- Effect on water transparency
- Maintaining ultrapure doped water
- Effects on detector components
- Introduction of new backgrounds for new and existing analysis

Which Compound To Use

- Three choices investigated thus far:
  - $Gd(NO_3)_3$
    - Easily dissolved
    - Nitrate opaque in the UV (very bad for Cherenkov light)
  - $GdCl_3$
    - Easily dissolved
    - Chloride highly corrosive (not good for components)
  - $Gd_2(SO_4)_3$
    - Not so easily dissolved
    - Good water transparency

Gadolinium sulfate is the compound to be tested at EGADS

Gd Pre-treatment System

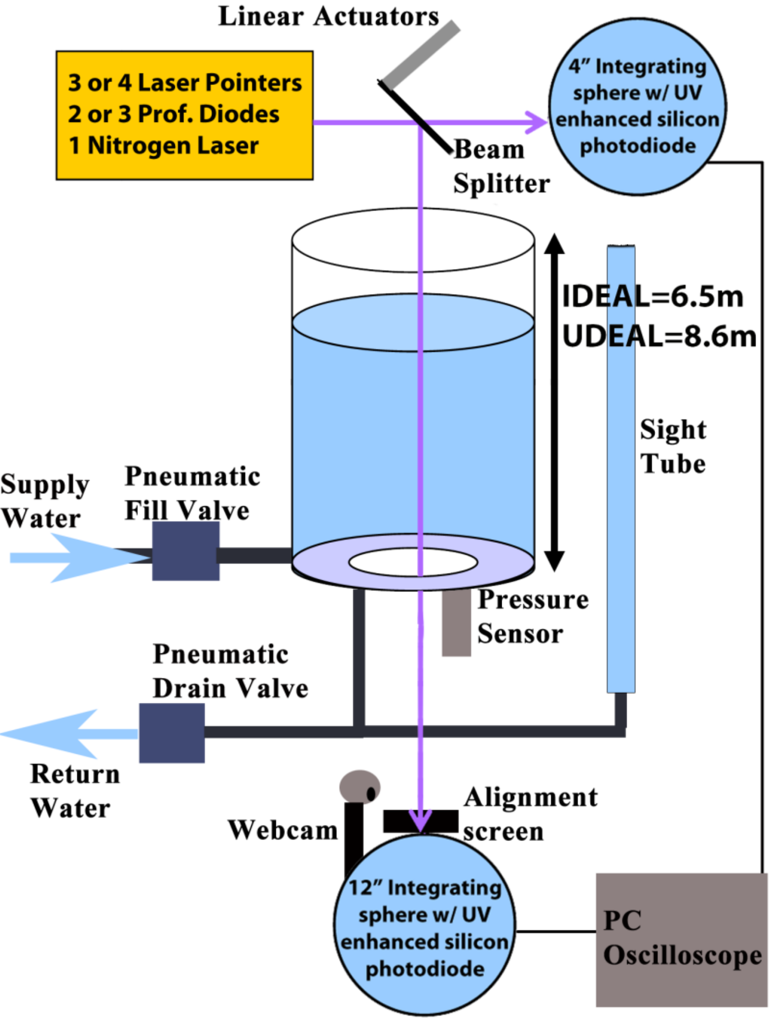
- $Gd_2(SO_4)_3$ **is soluble, but it needs a bit of help…**

15 m^3 tank to dissolve Gd

Sulfuric acid needed to dissolve, preliminary study shows ~4 L $H_2(SO_4)$ needed to make1% $Gd_2(SO_4)_3$ solution in the 15 m^3 tank

Simple water system with uranium removing resin tanks

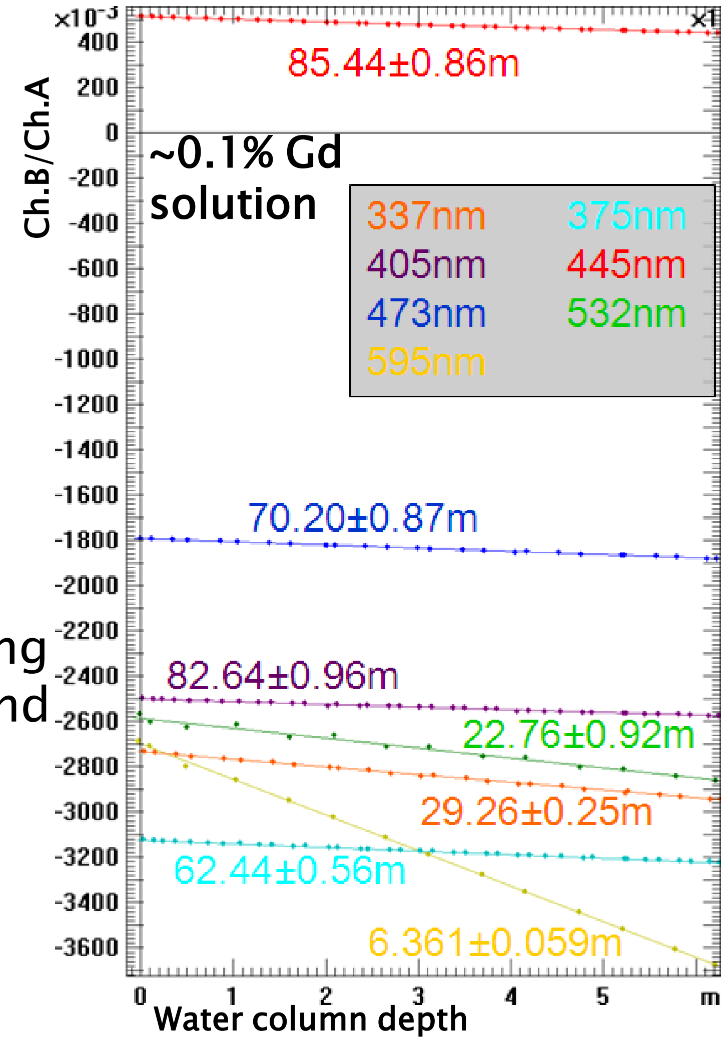
Water Transparency Monitoring



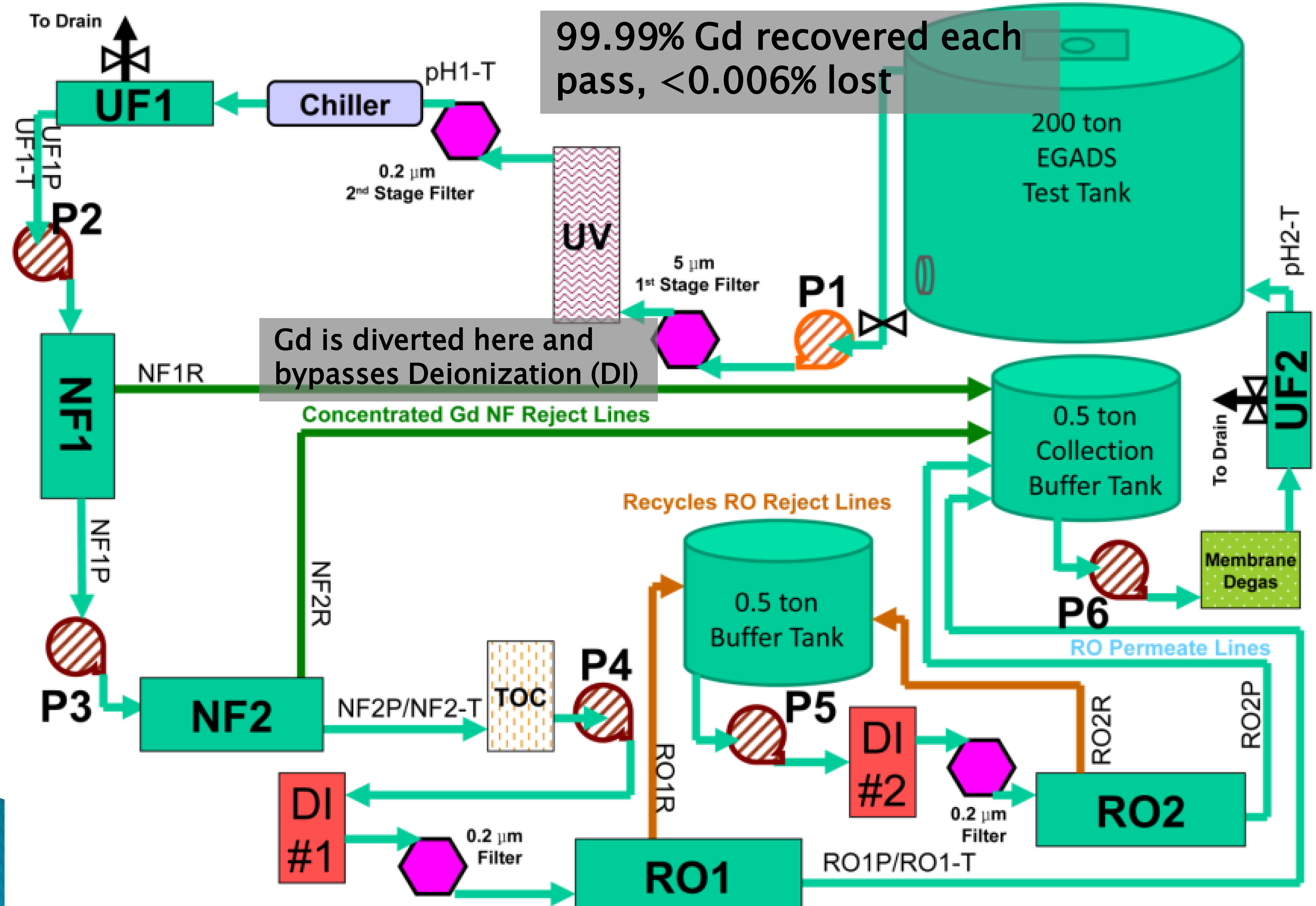
Precision measurements of attenuation lengths >100 m

Monitor relevant Cherenkov region using multiple lasers

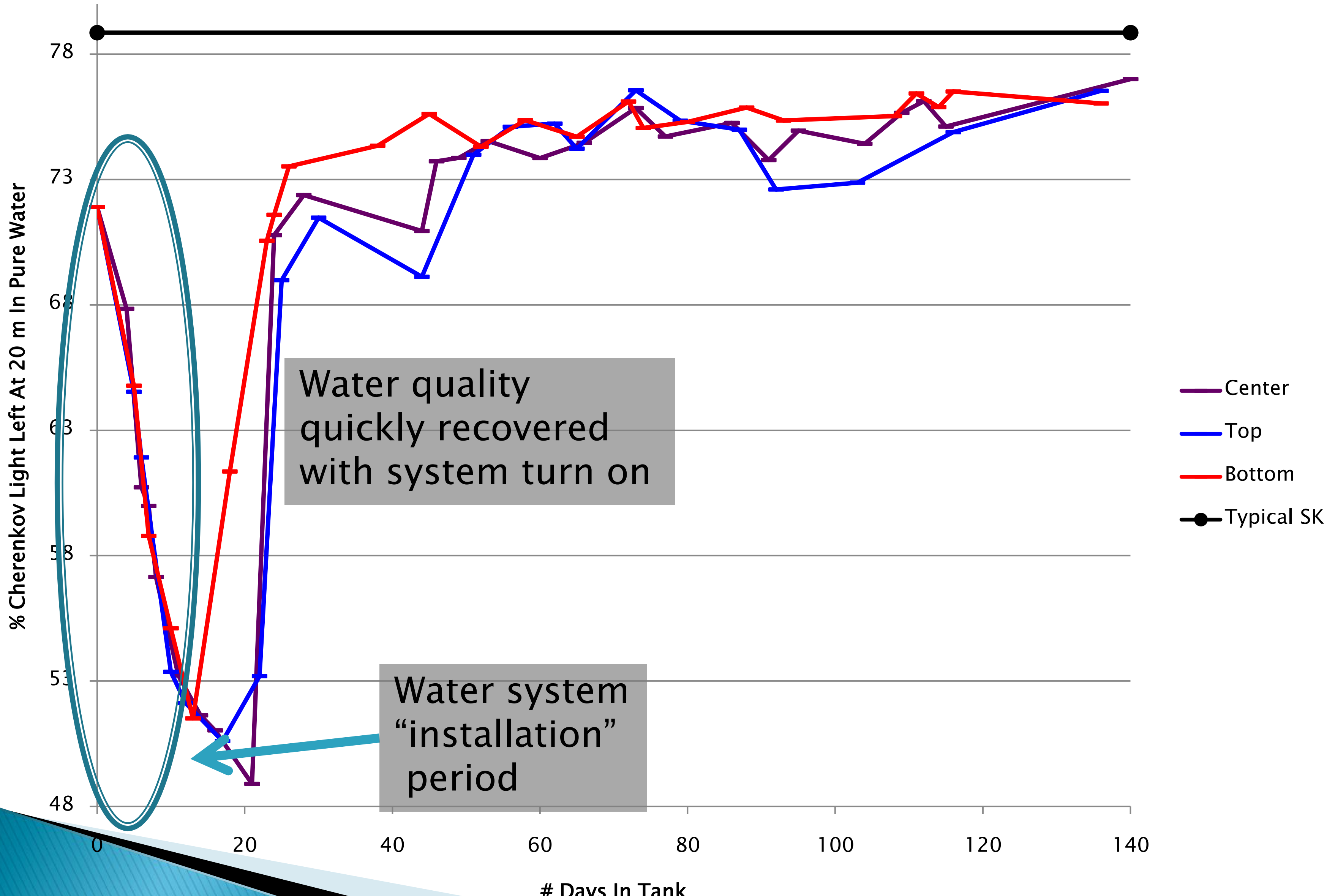
Devices fully automated, running is rather simple and quick



Selective Water Filtration



EGADS Water Transparency



Materials Effects

- 31 materials present in the SK tank have been soak tested in $Gd_2(SO_4)_3$ solution to check for corrosion.
- Only affected material is a rubber used for the FRP/acrylic cases.
- Further studies with this rubber show the effect is comparable to pure water if temperature is kept below 15°C.

Gd Removal

First method used at EGADS

Method 1: Ion exchange resin

Test shows Gd levels ~1000 ppm to less than 0.5 ppb

Resin will saturate, ok for small scale

Method 2: Removal system and filter press

pH up->Gd out of solution

Filter with a mechanical filter

Method still not perfected, but works well and is reusable

Only need to supply NaOH

SK Leak Fix

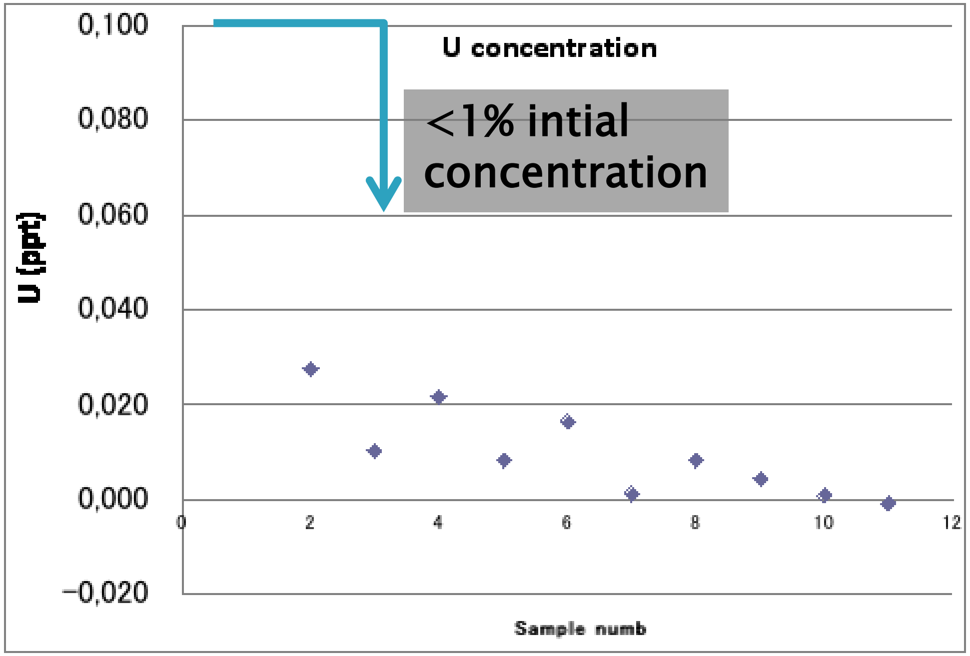
1. **Welding Method**
   - Company assures this will work
   - Will take much time
   - Can introduce more de-passivated welds
   - Introduce radioactive byproducts

2. **Epoxy Method**
   - Shorter fix time
   - Epoxy must be tested for strength and contamination
   - Strength test results are all positive
   - Contamination tests looking good

3. **Inner Bag/Acrylic Case**
   - Requires longest shutdown time and most work

Introduced Background Levels

- Background measurements of $Gd_2(SO_4)_3$ done at Canfranc show concentrations of U and Th at ~15 ppb and ~1 ppb (U chain more important).



<u>How to Fight This</u>

Pass Gd solution through special resin, saturates with Gd but not U

Only lose ~2% Gd, reduces U > 100x

Not so good with Th, but can ignore

Resin tanks part of pre-treat system

Sample above initially 10 ppt U, horizontal is # of BV of resin.

Ambient Neutron Levels

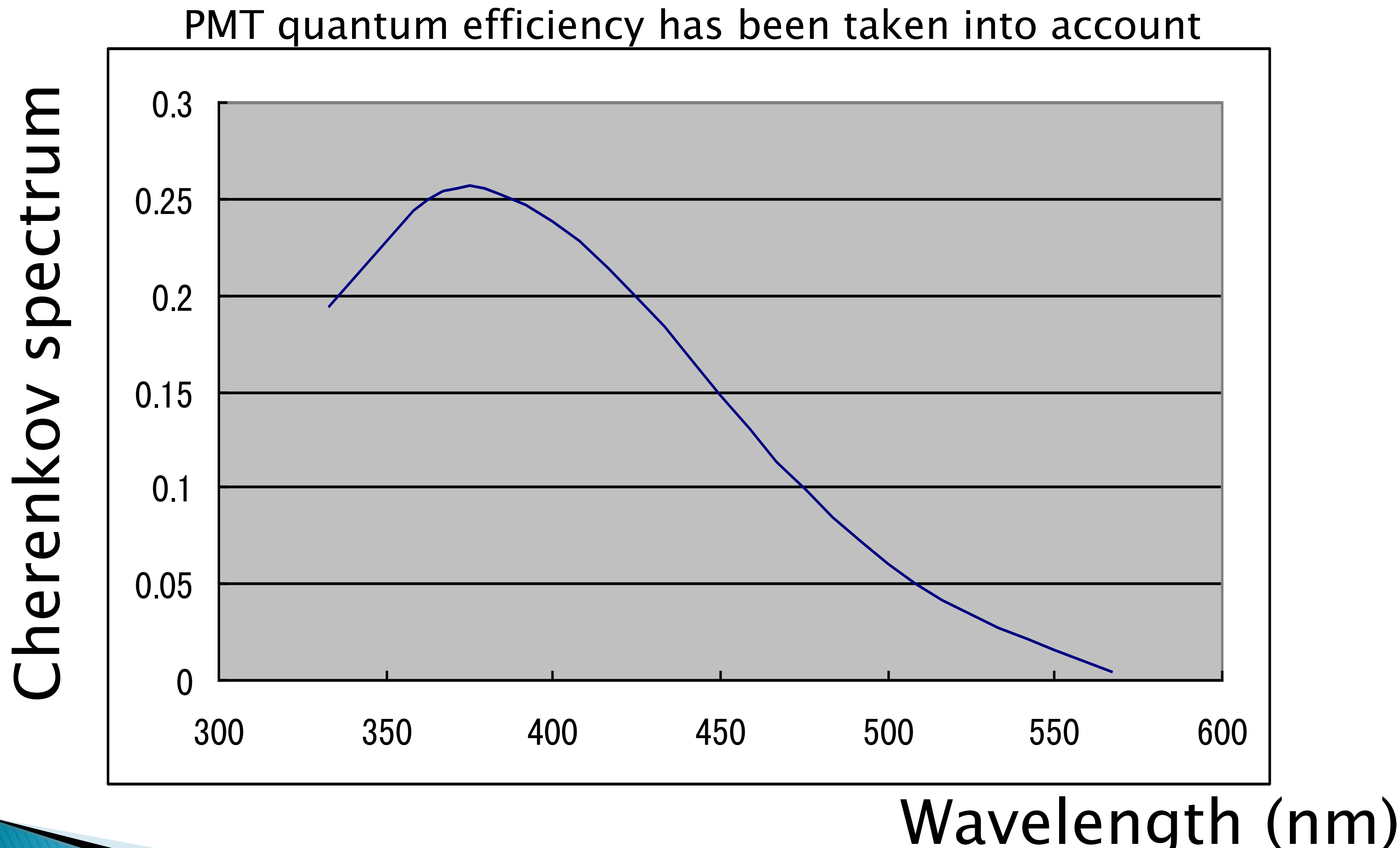
- If there are too many free neutrons in SK then adding Gd will make them all visible; this could introduce background for current studies.
- Initial studies show that isotropy information may distinguish neutron capture event from electron type event.
- Initial estimates claim these will not pose a problem, more studies will be done.

Immediate Future Plans

I. Add $Gd_2(SO_4)_3$ to the 15 m^3 tank within the next couple of weeks, first 0.2%
II. Recirculate the Gd solution through the water system and 15 m^3 tank (until happy)
III. Make concentrated solution in 15 m^3 tank
IV. Inject solution into 200 ton tank
V. Recirculate for some time (month or two)
VI. Drain 200 ton tank (large scale Gd removal test)
VII. Install 240 50 cm PMTs and DAQ
VIII. Refill tank and then I->IV

Backups

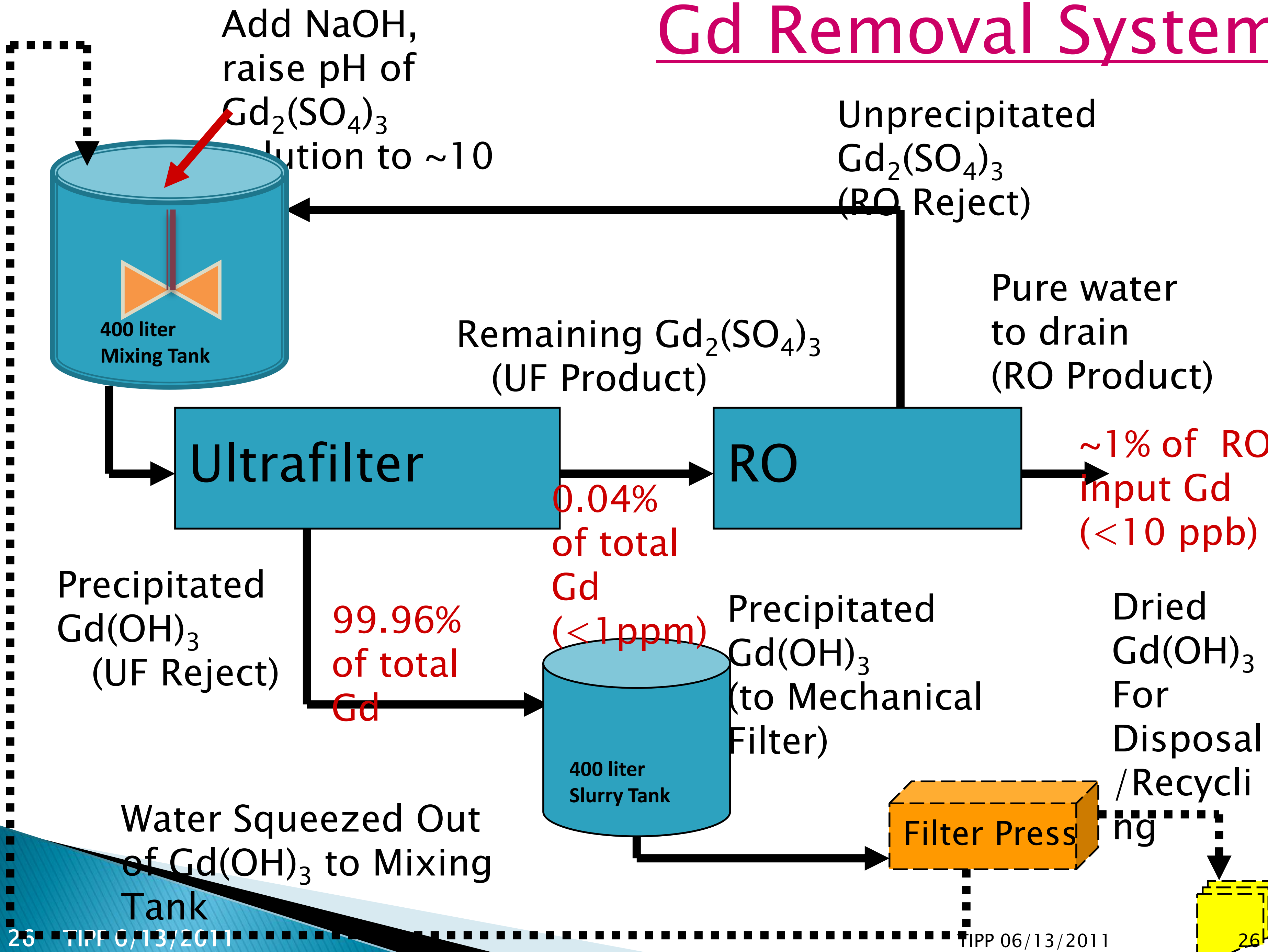
Cherenkov Spectrum In Pure Water



Selective Water Filtration

Membrane Type	Gd Remaining in Product Stream vs. Original Tank Concentration	SO_4 Remaining in Product Stream vs. Original Tank Concentration	Gd in Reject Streams	SO_4 in Reject Streams
NF Stage 1 (Nitto)	0.15%	<0.11%	99.85% (returned to "SK" by NF1)	>99.89% (returned to "SK" by NF1)
NF Stage 2 (Nitto)	<0.006% (this is what is lost)	<<0.11%	>99.994% (returned to "SK" by NF1+NF2)	>>99.89% (returned to "SK" by NF1+NF2)

Gd Removal System



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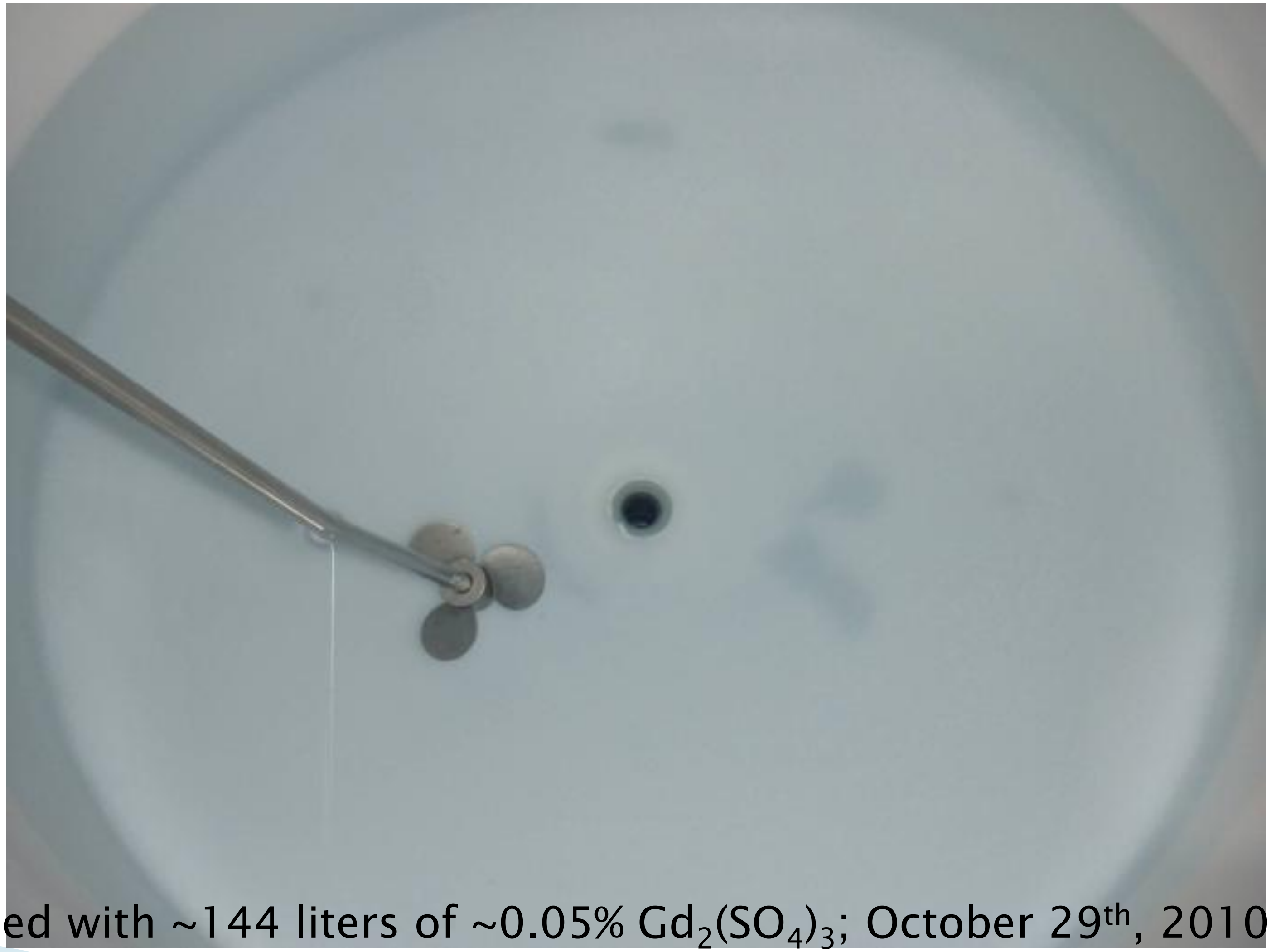
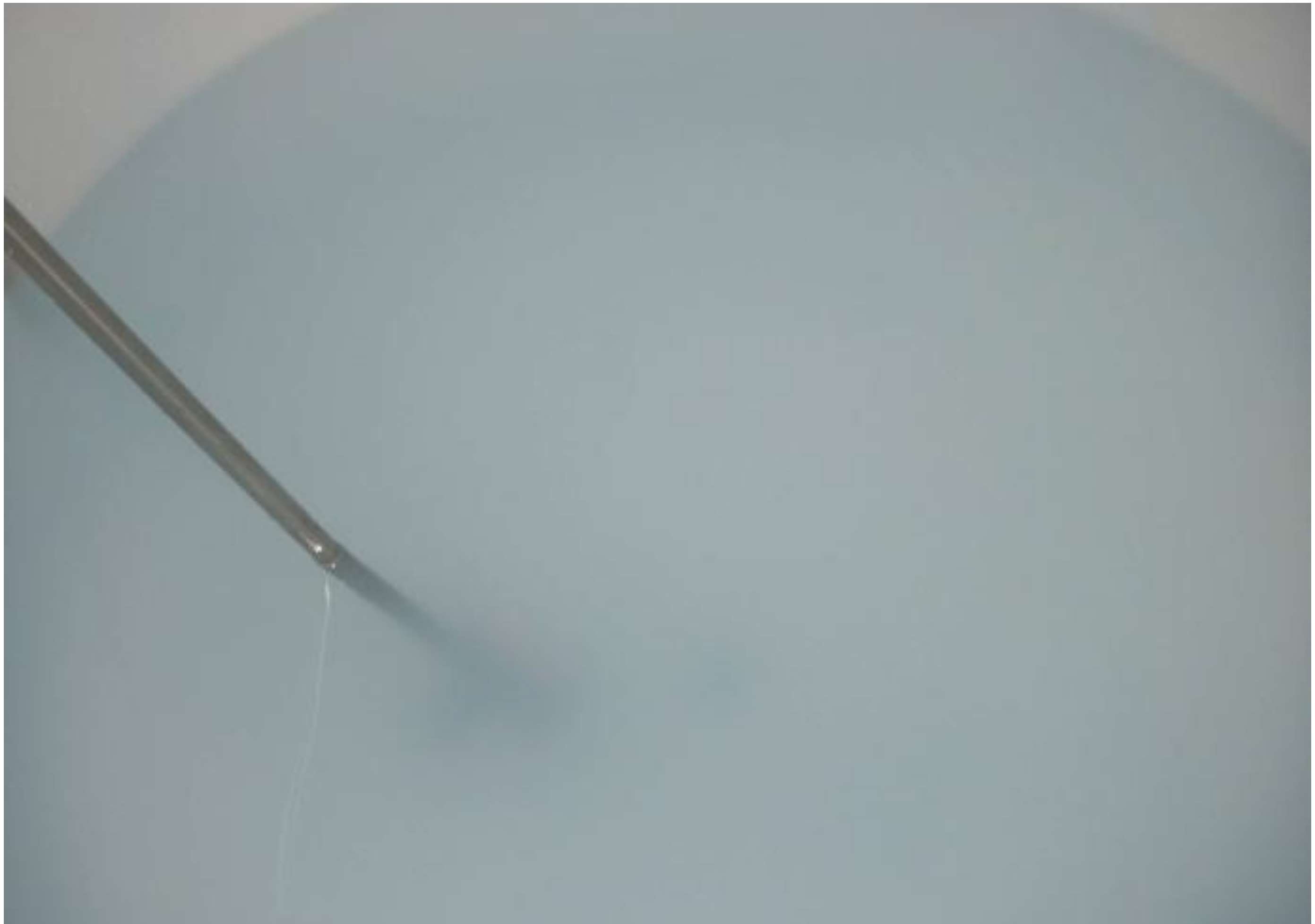
Removing Gd



Filled with ~144 liters of ~0.05% $Gd_2(SO_4)_3$; October 29th, 2010

Removing Gd

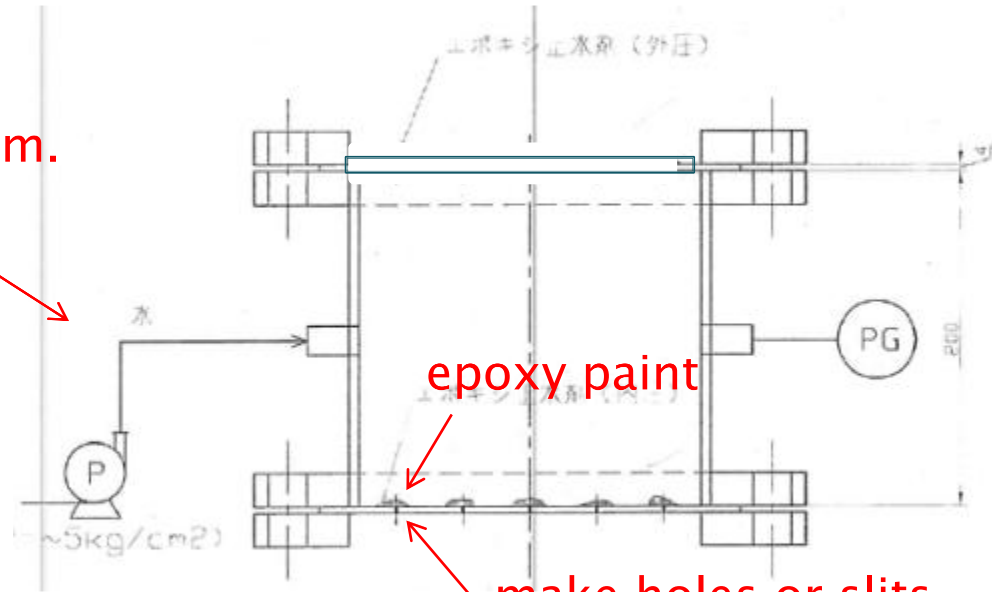


After adding 1.0 M NaOH (stirrer is off); October 29th, 2010

Epoxy Strength Test

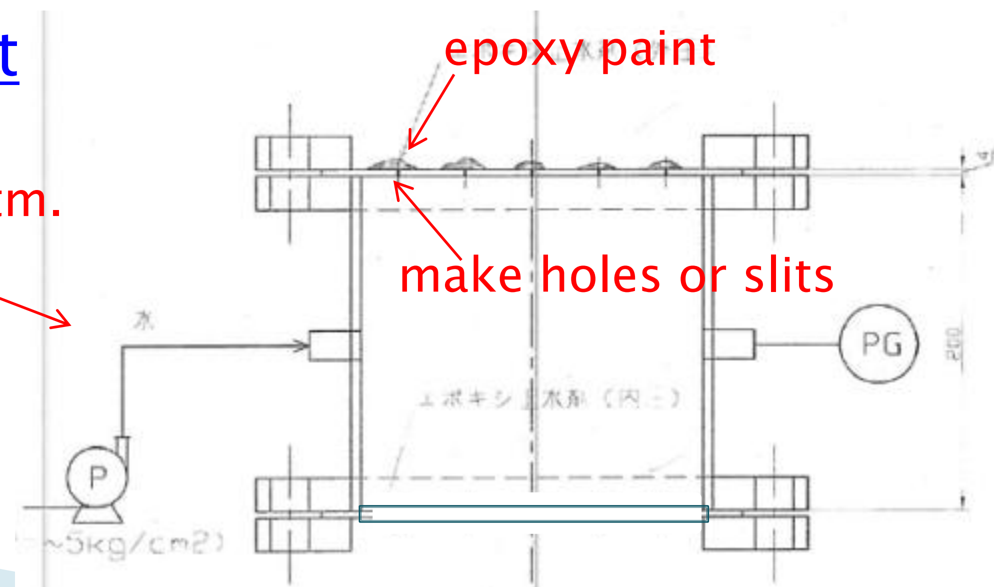
Positive pressure test

Pressurize upto 5 atm.

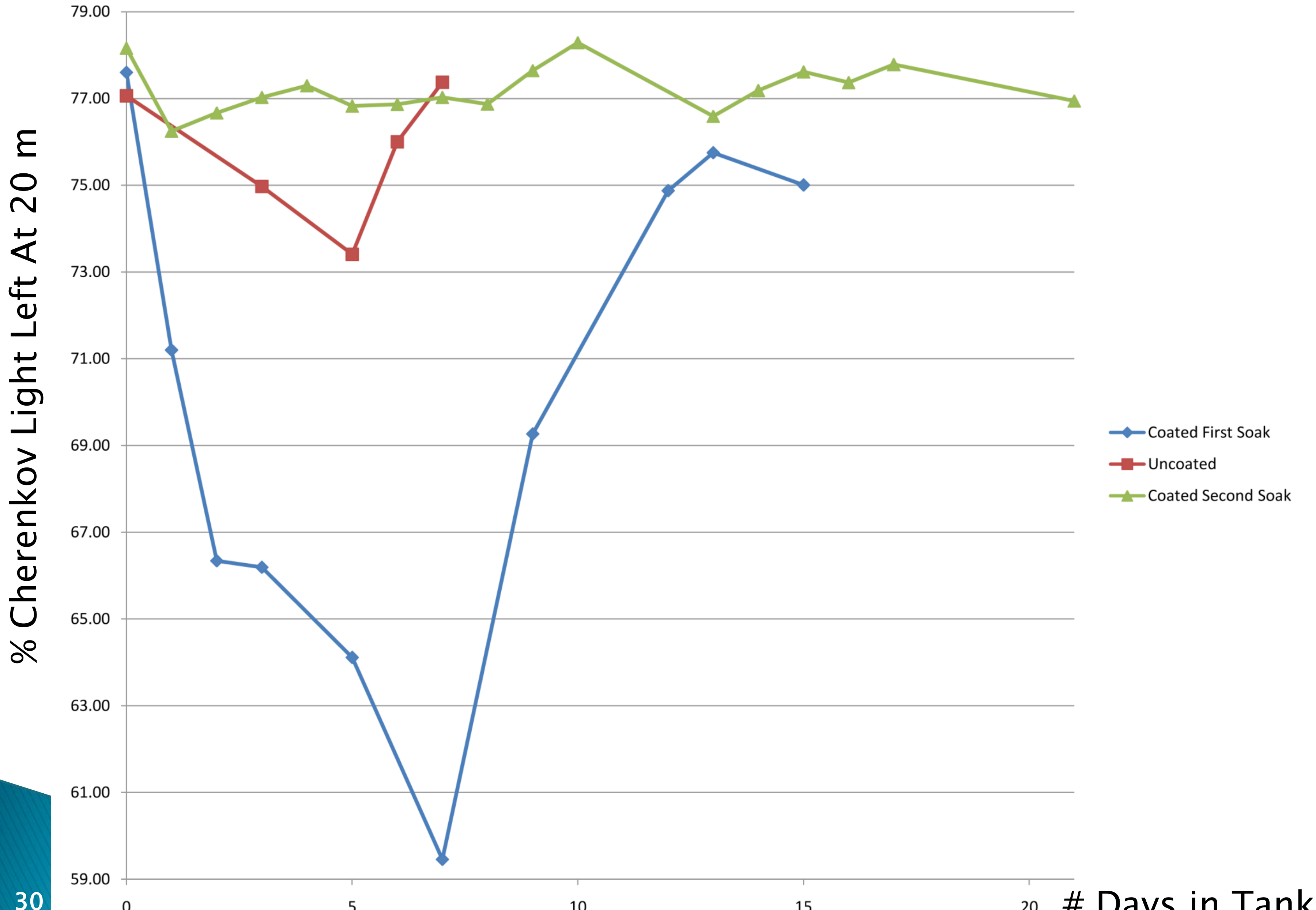


Negative pressure test

Pressurize upto 0.1 atm.



Epoxy Soak Test



PMT Isotropy (β_{14})

- We can define an isotropy parameter (SNO called it β_{14}) that is related to the angular distribution of hit PMTs.

$$\beta_{14} = \beta_1 + 4\,\beta_4$$

where

$$\beta_l = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} P_l(\cos\theta_{ij}).$$

N: Number of hit PMTs

P_l: Legendre polynomial of order l

θ_{ij}: Angle between triggered PMTs i and j relative to the event vertex

- Higher isotropy → lower β_{14}

(B. Aharmim *et al.*). 2010

SK MC Simulations