# METAL LOADING IN ORGANIC LIQUID SCINTILLATOR

Mark Chen
Queen's University and CIFAR

TAUP 2017 "New Technologies" session
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# TALK OUTLINE

- metal-loaded scintillators >20 years ago
- carboxylate and acac
- nanoparticles
- water-based loadings
- new technique for loading tellurium

# GD-LOADED SCINTILLATOR >20 YEARS AGO

PHYSICAL REVIEW C VOLUME 52, NUMBER 6 DECEMBER 1995

**Muon-induced neutron and pion production in an organic liquid scintillator at a shallow depth**

R. Hertenberger* and M. Chen†
*Norman Bridge Laboratory of Physics, California Institute of Technology, Pasadena, California 91125*

B. L. Dougherty‡
*Department of Physics, Stanford University, Stanford, California 94305*
(Received 4 May 1995)

The production of fast neutrons and pions by inelastic interactions of cosmic-ray muons in an organic liquid scintillator has been investigated. A detector filled with 190 liters of a 0.09% gadolinium-loaded liquid scintillator was installed in the Stanford Underground Facility, at an underground depth of approximately 20 meters water equivalent. The detector served as the target material for hadron production. Our measurements find a

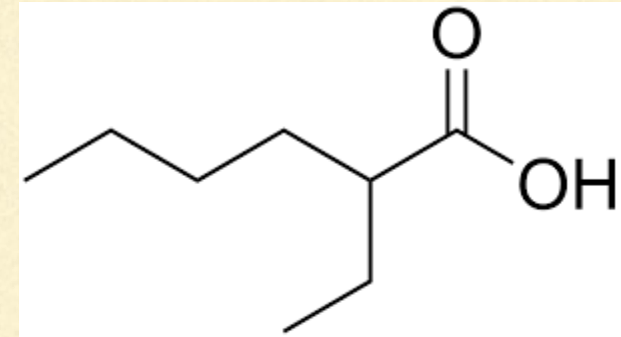
Gd-loaded scintillator for CHOOZ and the cocktail we made (intended for San Onofre) used alcohols to dissolve the Gd; enabled mixing with organic solvents like pseudocumene in mineral oil.

# CHOOZ HEP-EX/0301017

**Table 5.** Main properties of the liquid scintillators used in the experiment.

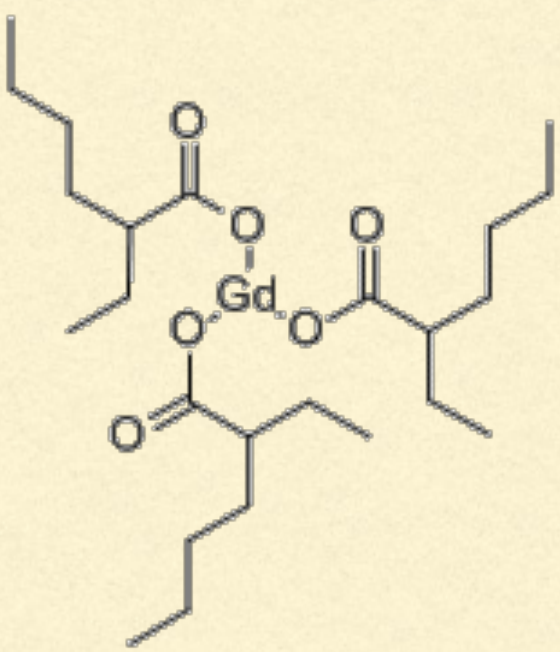
| | Gd-loaded | unloaded |
|---|---|---|
| Chemical content: | | |
| basic | Norpar-15 (50% vol.) | Mineral oil (92.8% vol.) |
| aromatics, alcohols | IPB+hexanol (50% vol.) | IPB (7.2% vol.) |
| wavelength shifters | p-PTP+bis-MSB (1 g/l) | PPO + DPA (1.5 g/l) |
| Atomic mass composition: | | |
| H | 12.2% | 13.3% |
| C | 84.4% | 85.5% |
| Gd | 0.1% | |
| others | 3.3% | 1.2% |
| compatibility | acrylic, Teflon | |
| density (20 °C) | 0.846 g/ml | 0.854 g/ml |
| Flash point | 69 °C | 110 °C |
| Scintillation yield | 5300 ph/MeV (35% of anthracene) | |
| Optical attenuation length | 4 m | 10 m |
| Refractive index | 1.472 | 1.476 |
| Neutron capture time | 30.5 $\mu$s | 180 $\mu$s |
| Neutron capture path length | $\sim$ 6 cm | $\sim$ 40 cm |
| Capture fraction on Gd | 84.1% | |

# CARBOXYLATE




## Palo Verde Gd-loaded liquid scintillator used gadolinium 2-ethylhexanoate

"…widely used to prepare lipophilic metal derivatives that are soluble in non-polar organic solvents." Wikipedia




**Development of a Gd Loaded Liquid Scintillator for Electron Anti-Neutrino Spectroscopy**

Andreas G. Piepke[1], S. Wayne Moser[2] and Vladimir M. Novikov[1,3]

[1] *Department of Physics 161-33, Caltech, Pasadena, CA 91125, USA*
[2] *Bicron/SGIC Inc., Newbury, OH 44065, USA*
[3] *Institute of Nuclear Research, 117312 Moscow, Russia*

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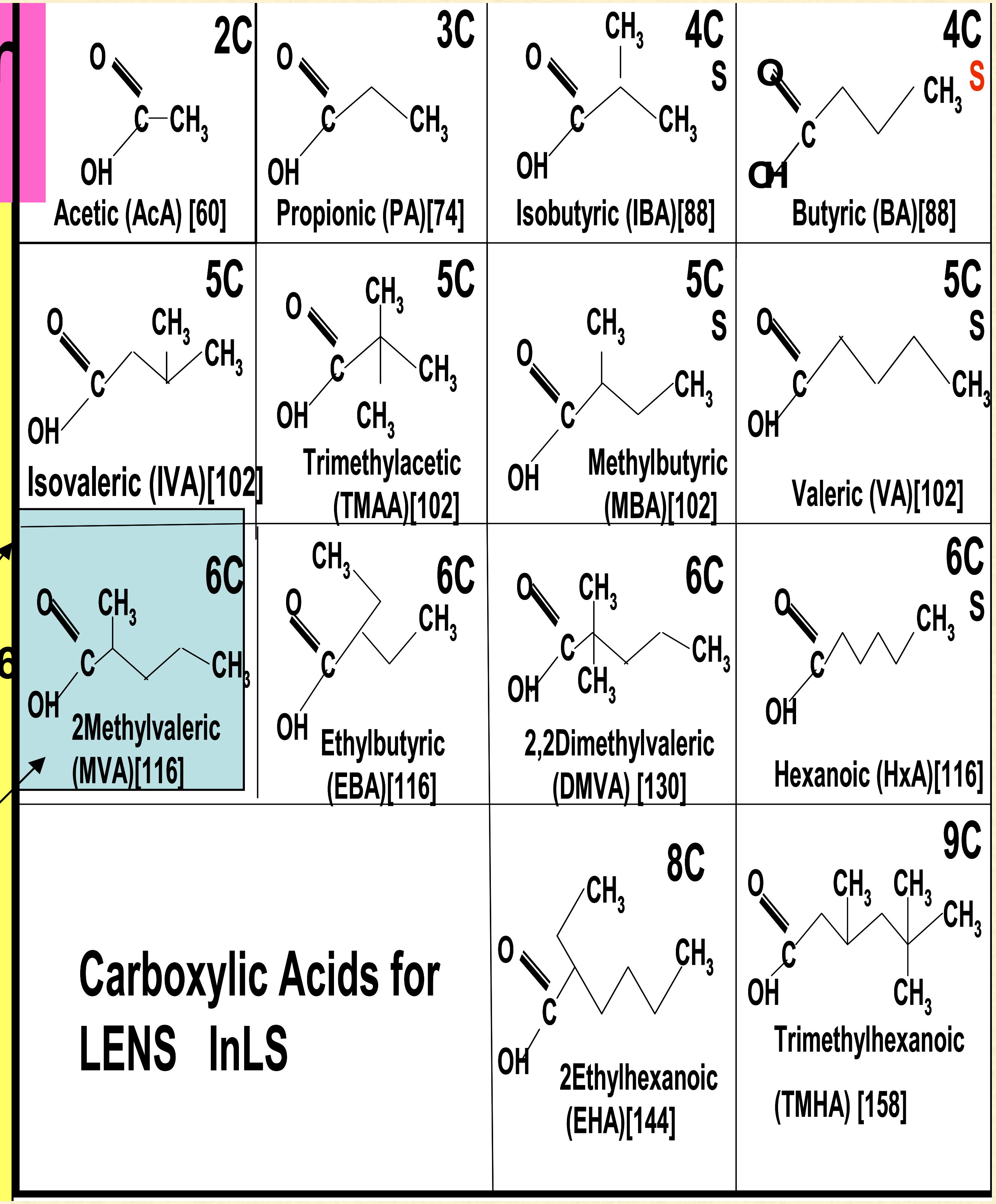
# InLS Chemistry:Search for In organo-metallic cmpd.

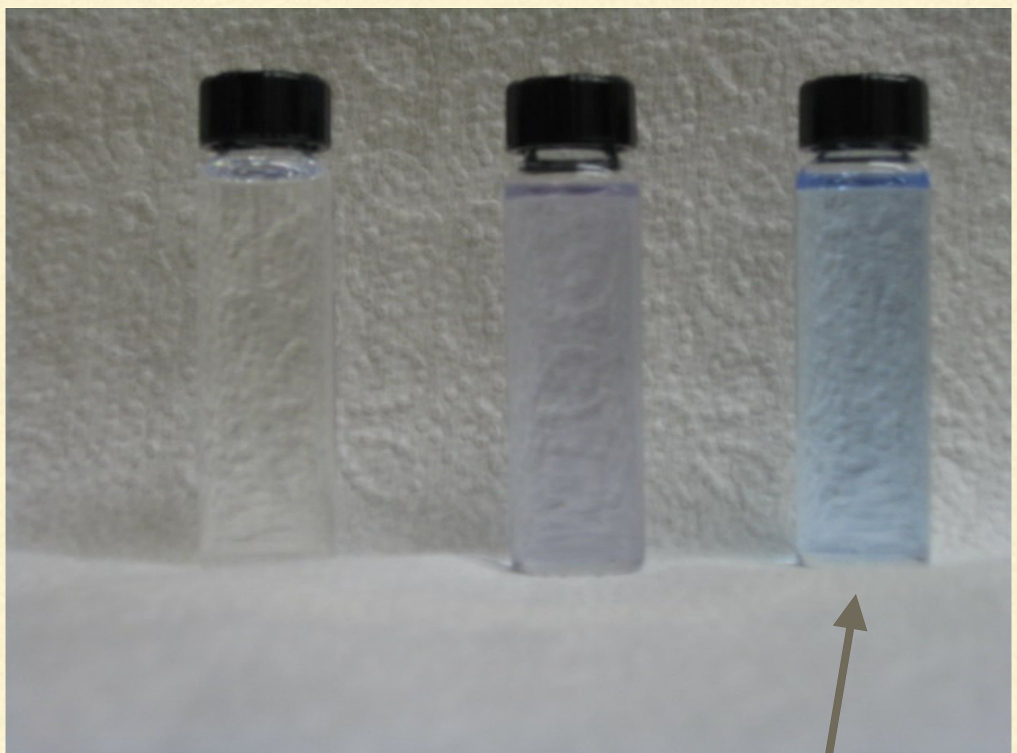
**Basic Approach for Indium Loading:**
**In- organo-metallic compound**
**Best choice:- In-carboxylates**

- **Pioneered in Fifties by Reines group with Gd octaonate for *low* Gd loading**
- **Key for *hi metal* loading –*Use Low Mass* Carboxylates first studied @ Bell Labs1996**
- **Systematic study (~1000 samples synthesized) of most low mass RC02H**
- **Loading of (Gd, Yb, Pb, In) achieved**
- **Basic US Patent: Chandross & RSR filed 2001-awarded-04)**
- **Best Case : 2-Methylvaleric acid-**
- **Milestones In-MVA-LS for solar neutrino observations set by *Bell Labs- VT, [INR IPC (Moscow)-LNGS], BNL***




Slide from Raju Raghavan @ INT Workshop on “Exploring the Physics Frontier at Deep Underground Labs”, June 2005

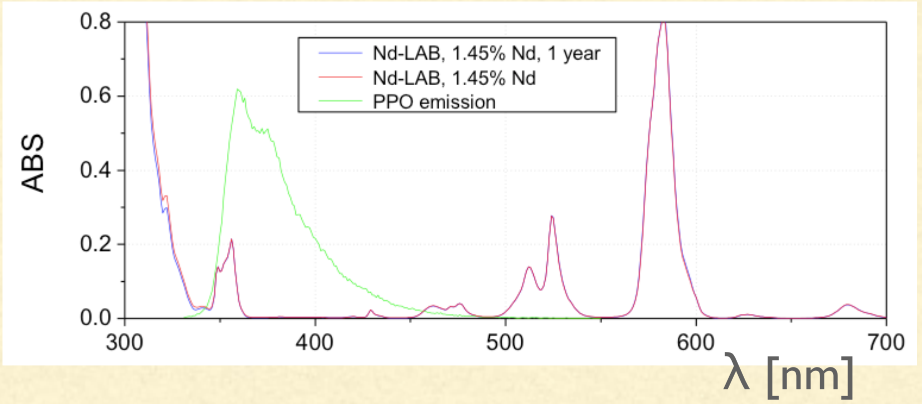
# APPLICATIONS OF CARBOXYLATE LOADING TECHNIQUE



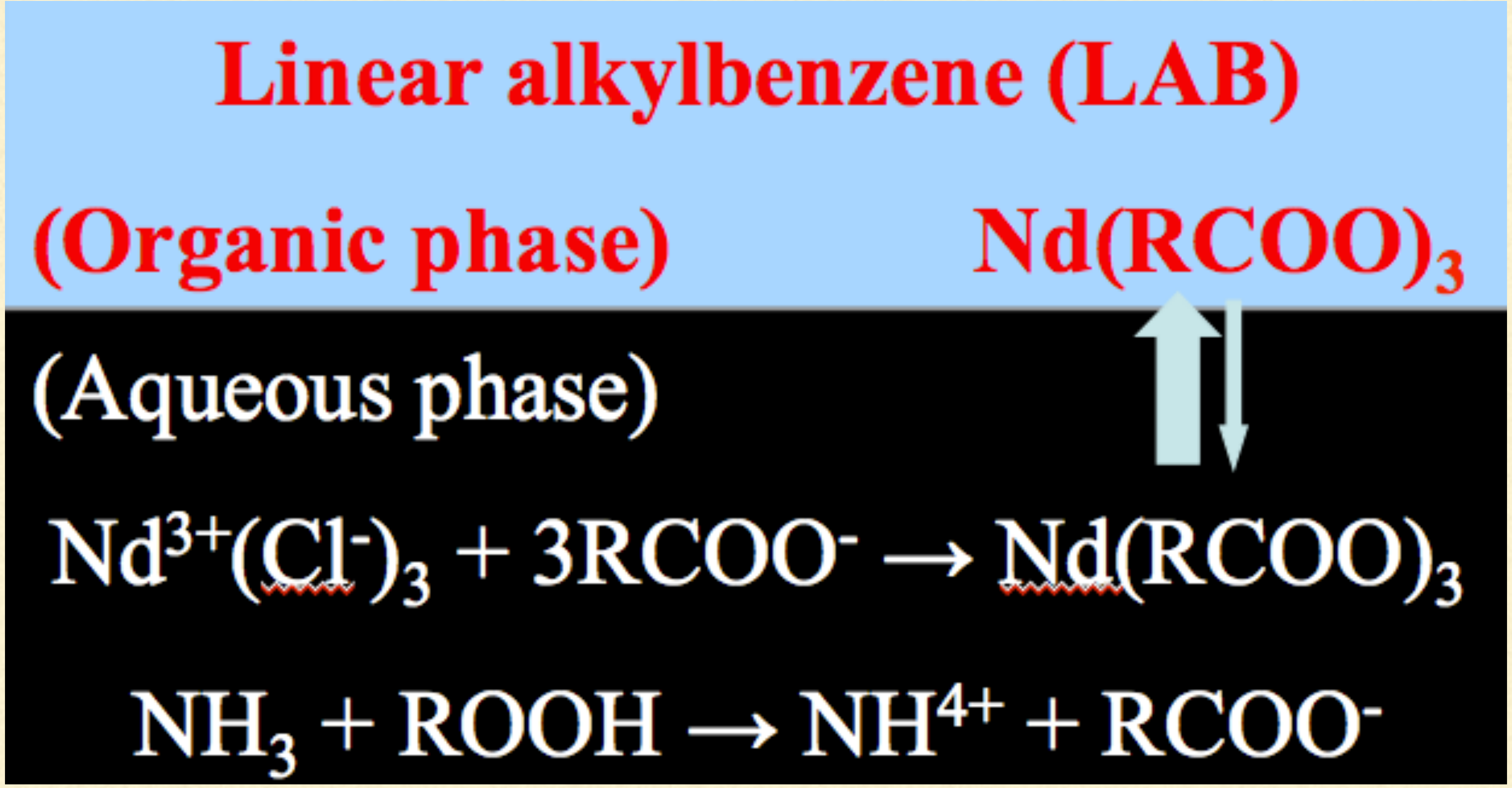
1% Nd in LAB made at Queen's

- Gd liquid scintillator for antineutrino IBD detection (e.g. Daya Bay, RENO)
- LENS: In-loaded and Yb-loaded liquid scintillator for low-energy solar neutrinos
- Nd-loaded liquid scintillator for SNO+ double beta decay $^{150}$Nd
- $^{6}$Li-loaded liquid scintillator for neutron detection

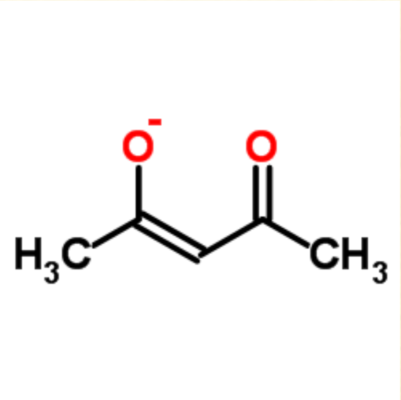
# ND-LOADING IN LAB



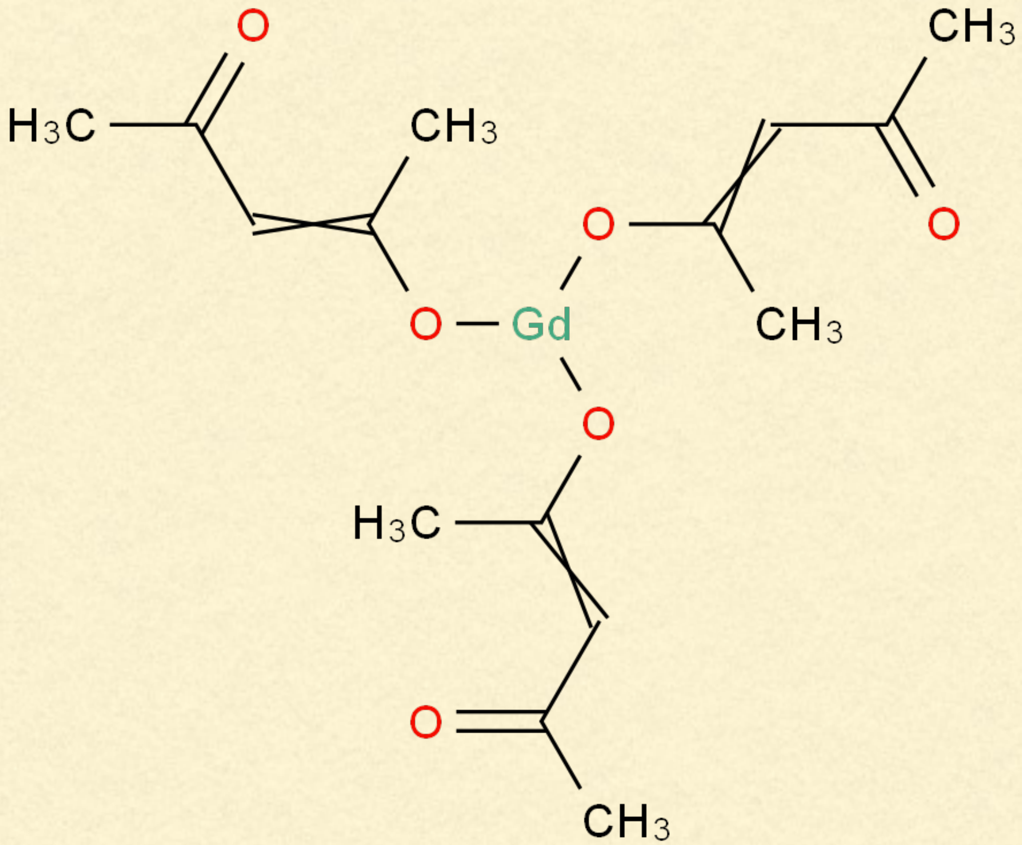

- pH control in the aqueous phase is important (BNL)



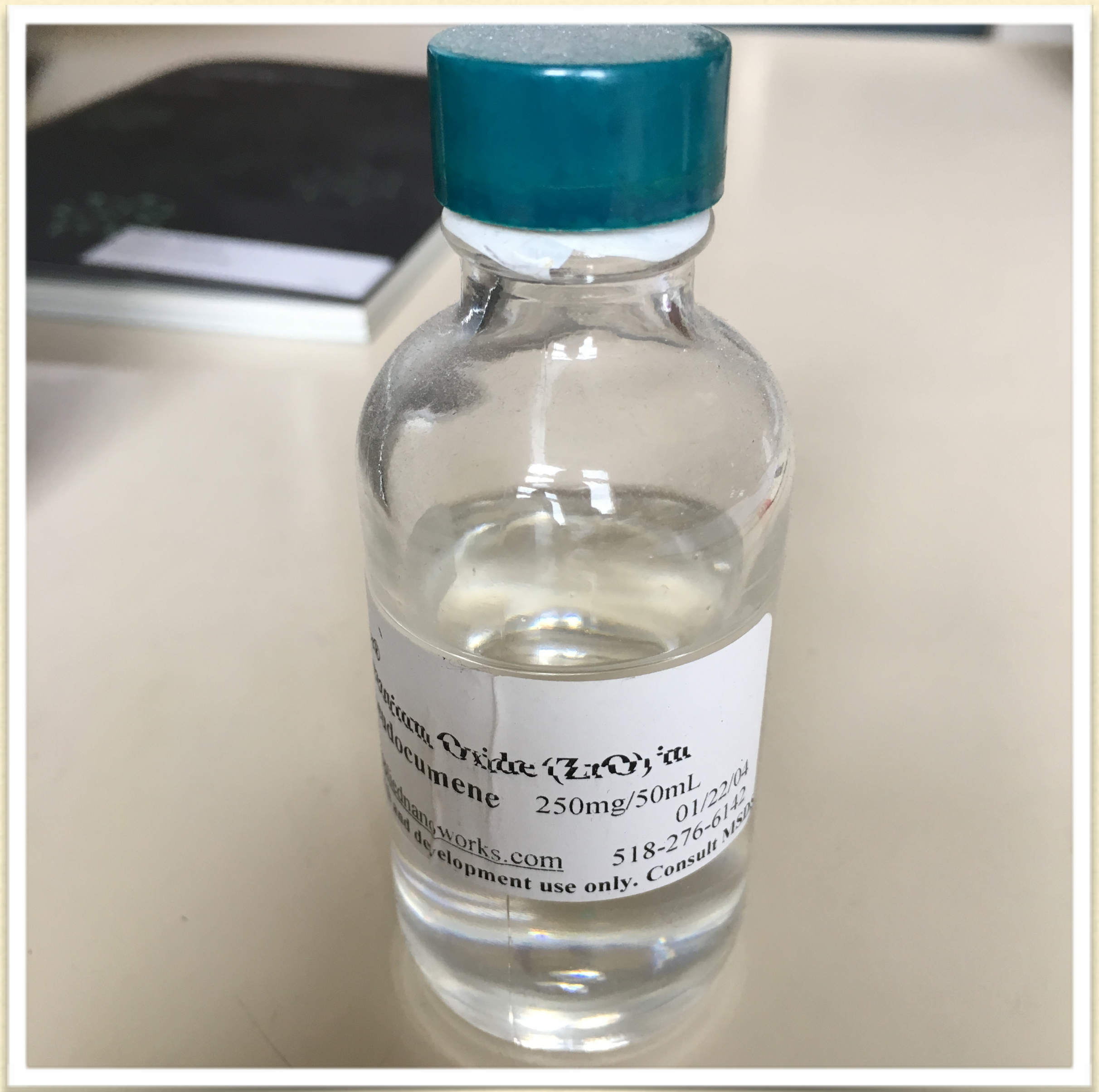
# ACETYLACETONATE (ACAC)




- Double Chooz Gd-loaded scintillator used the acac metal-loading technique
- initiated by F.X. Hartmann (I think)



# NANOPARTICLES




- nanoparticles can be suspended in organic liquids (R&D at Queen's initiated in 2002)
  - as double beta decaying isotope (e.g. ZrO)
  - as optically active scintillating crystals or scintillating quantum dots (e.g. CdSe)

# NANOPARTICLE CHALLENGES

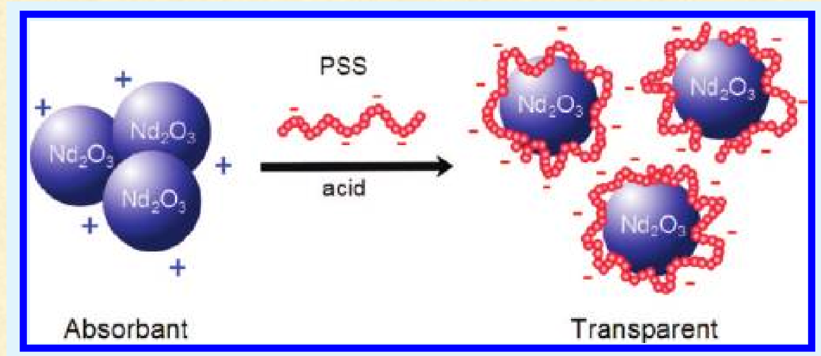
- materials/polymer R&D to ***stabilize*** (prevent aggregation, self-assembly, precipitating)
- layering and multi-layering of polyelectrolytes onto metal and metal inorganic surfaces

ACS APPLIED MATERIALS & INTERFACES
RESEARCH ARTICLE
www.acsami.org

**Stabilization of Neodymium Oxide Nanoparticles via Soft Adsorption of Charged Polymers**

Annie Dorris,[†] Clémence Sicard,[†] Mark C. Chen,[‡] Arthur B. McDonald,[‡] and Christopher J. Barrett*[,†]

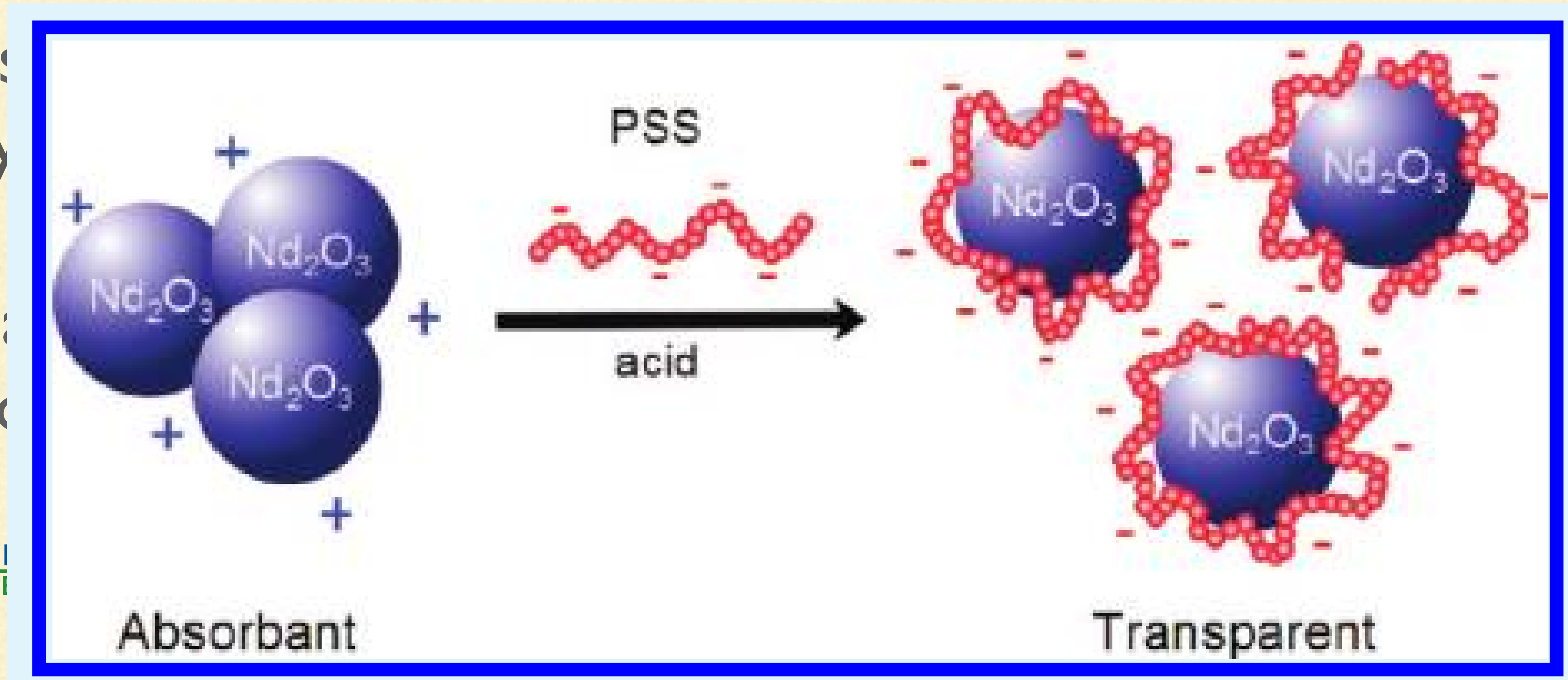
[†]Department of Chemistry, McGill University, Montreal, Canada
[‡]Department of Physics, Engineering Physics and Astronomy, Queen's University, Kingston, Canada




PSS poly(styrene sulfonate)

# NANOPARTICLE CHALLENGES

- materials … -
  assembly …
- layering … l
  metal in…




ACS APPLIED MAT… & INT…

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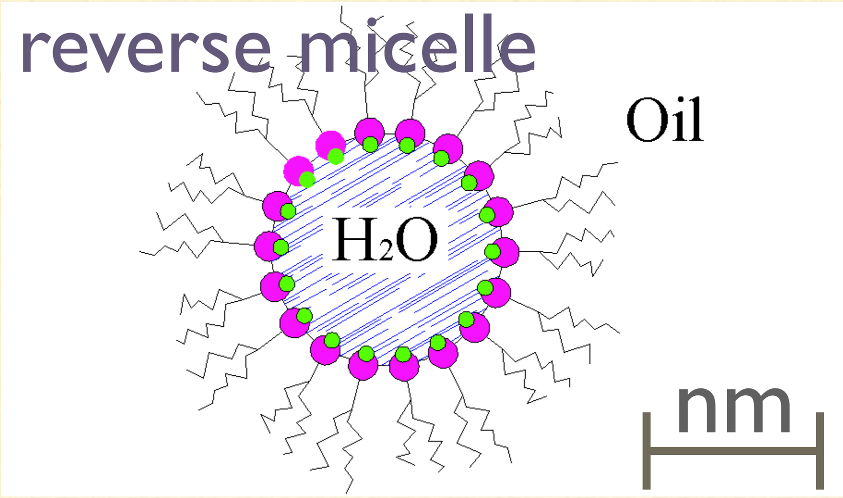
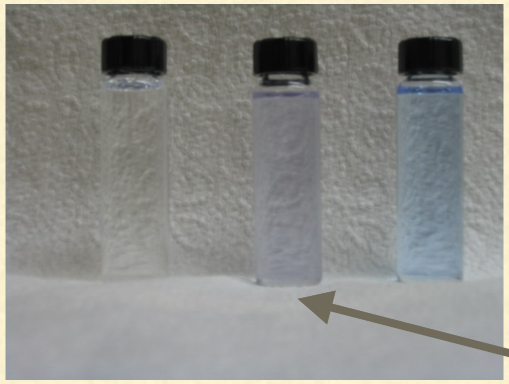
PSS poly(styrene sulfonate)

# WATER-BASED LOADING

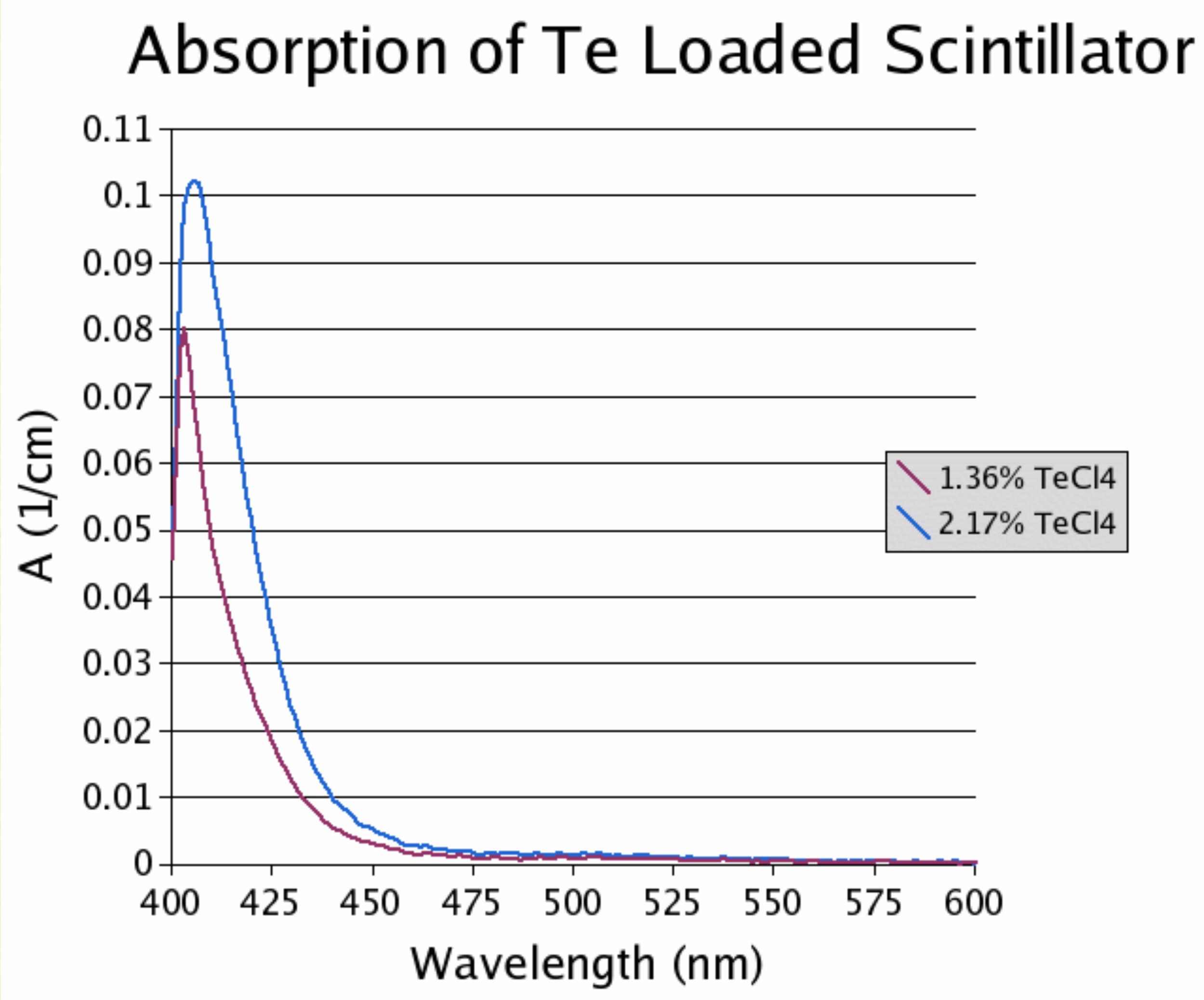
- similar, in concept, to nanoparticle loading
- commercially available
  - e.g. Quicksafe (Zinsser Analytic)
- Triton X-100 surfactant is common
- LAS-based (linear alkylbenzene sulfonate) b/c LAB
  - basis of WbLS recently developed by M. Yeh @ BNL
- other surfactants – anionic, cationic, nonionic – can be considered



NdCl3 in Quicksafe made at Queen's

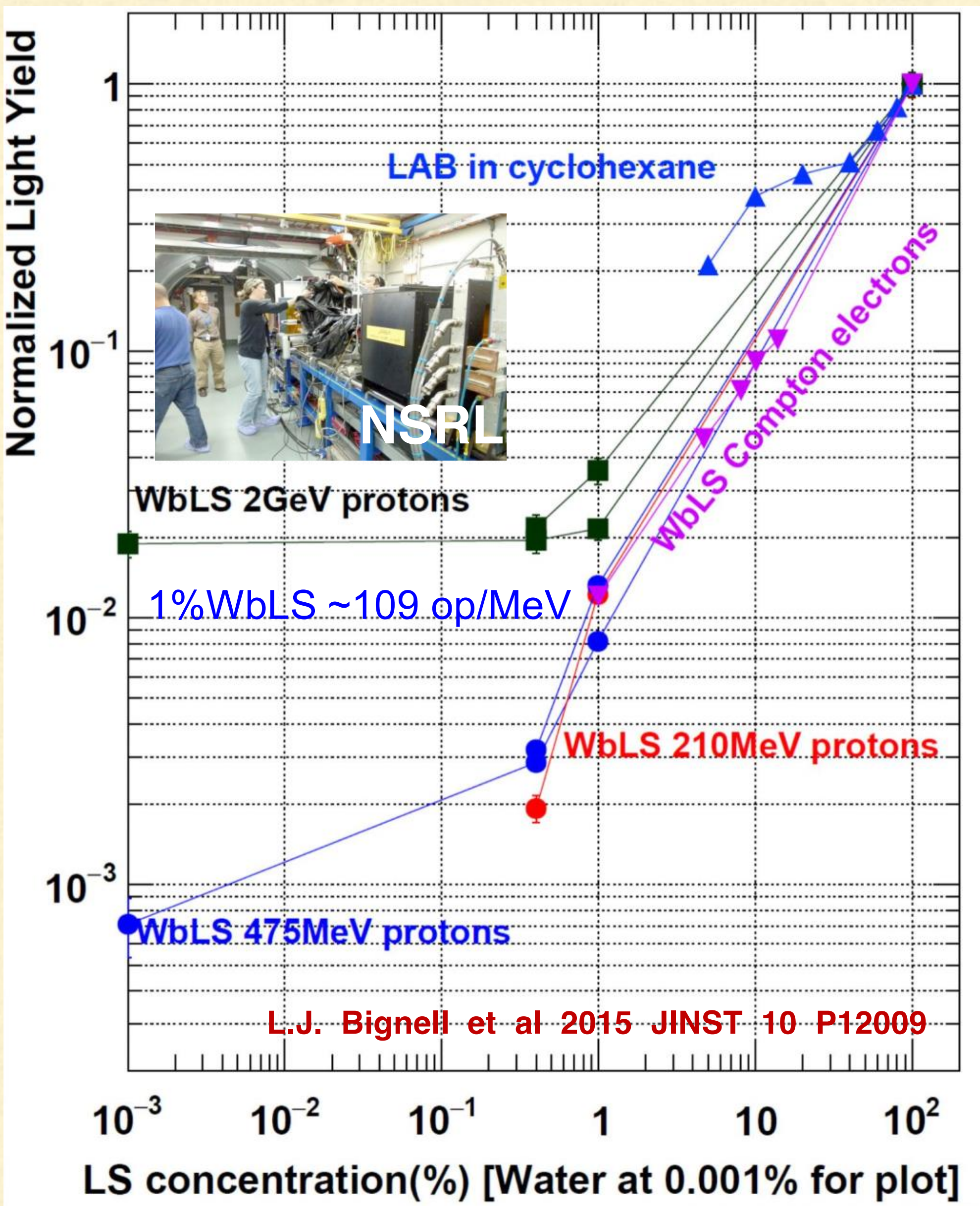
# TE-LOADED IN QUICKSAFE



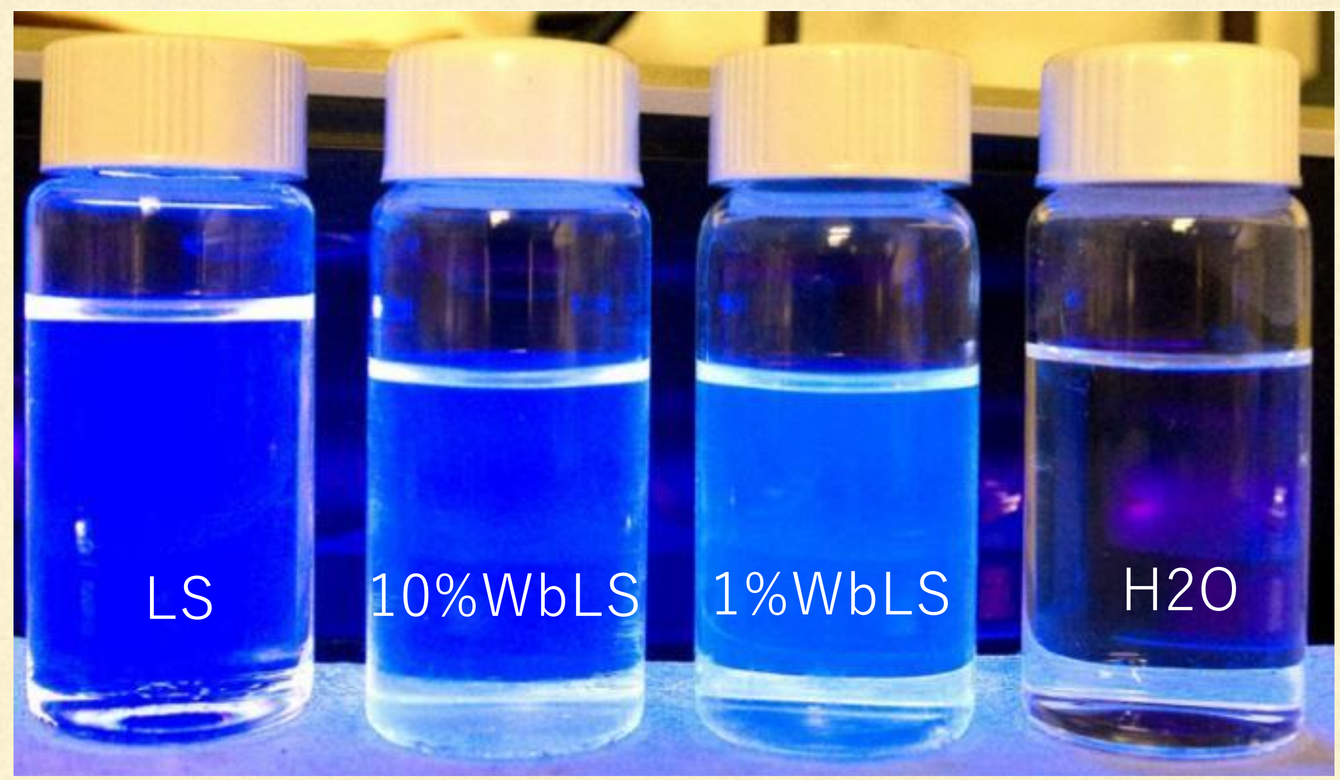

- $TeCl_4$ "absorption" (2005 sample prepared at Queen's)
  - Quicksafe absorption has been subtracted
  - no absorption features
  - consistent with light scattering (off reverse micelles)

# WbLS RESULTS FROM BNL

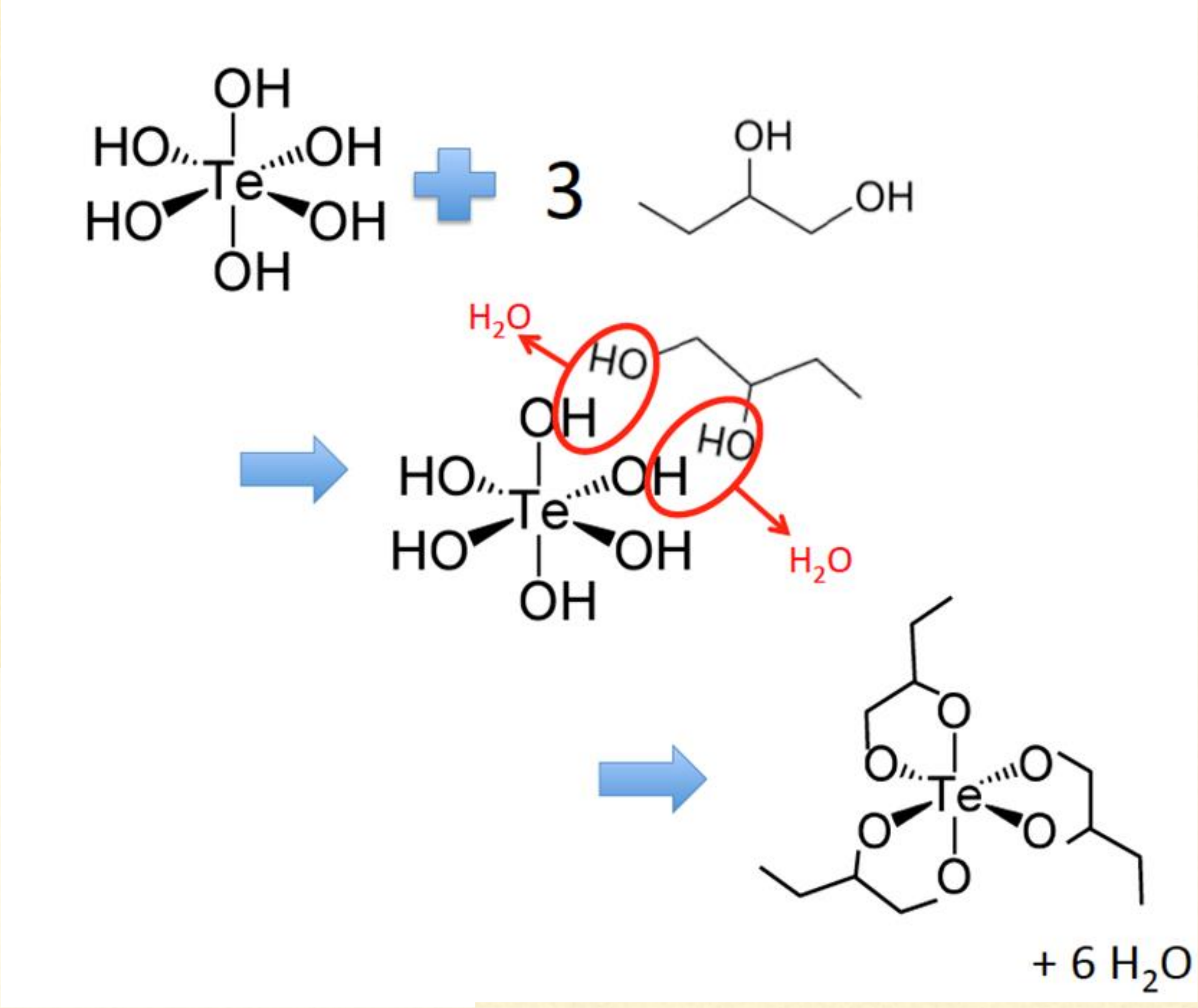
*from M.Yeh*

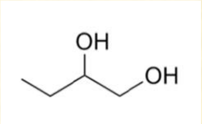



- normalized light yield scales as LS concentration
  - ***…and not worse!***



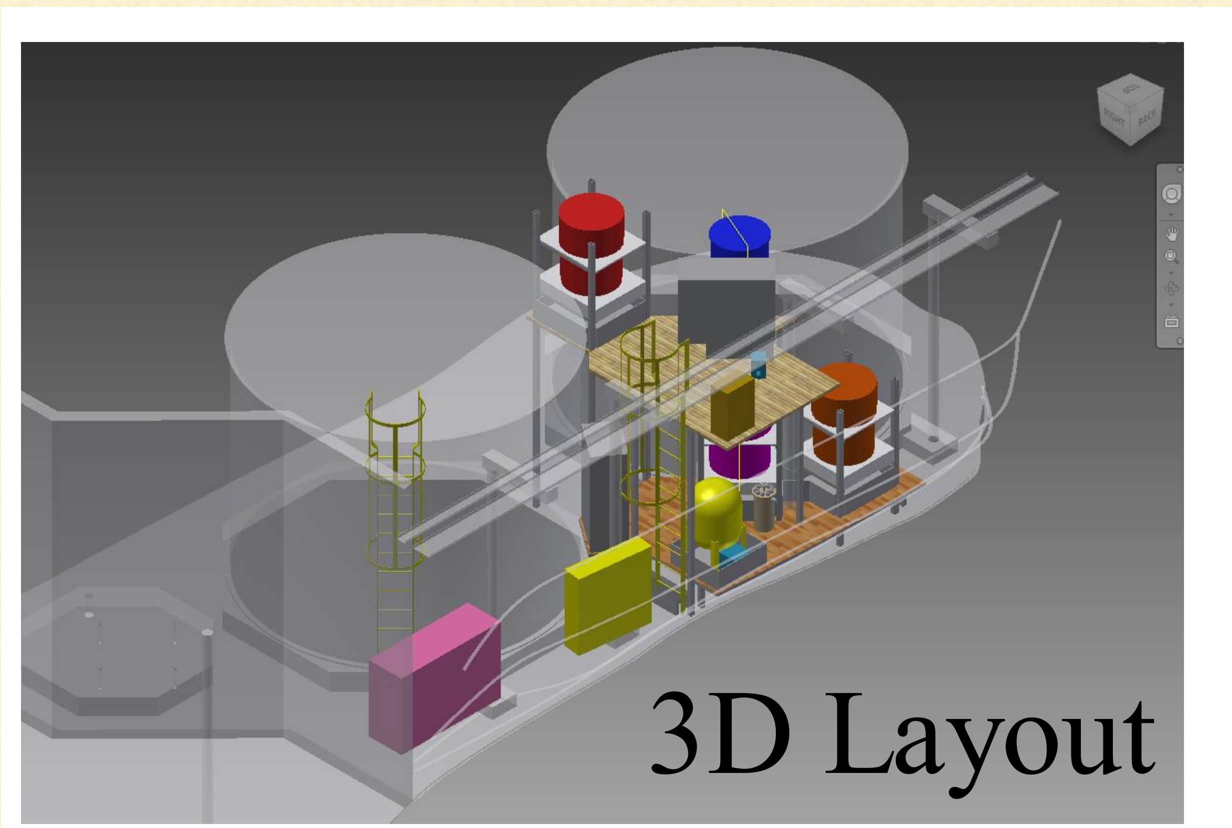
# TELLURIUM-LOADED LIQUID SCINTILLATOR (FOR SNO+)

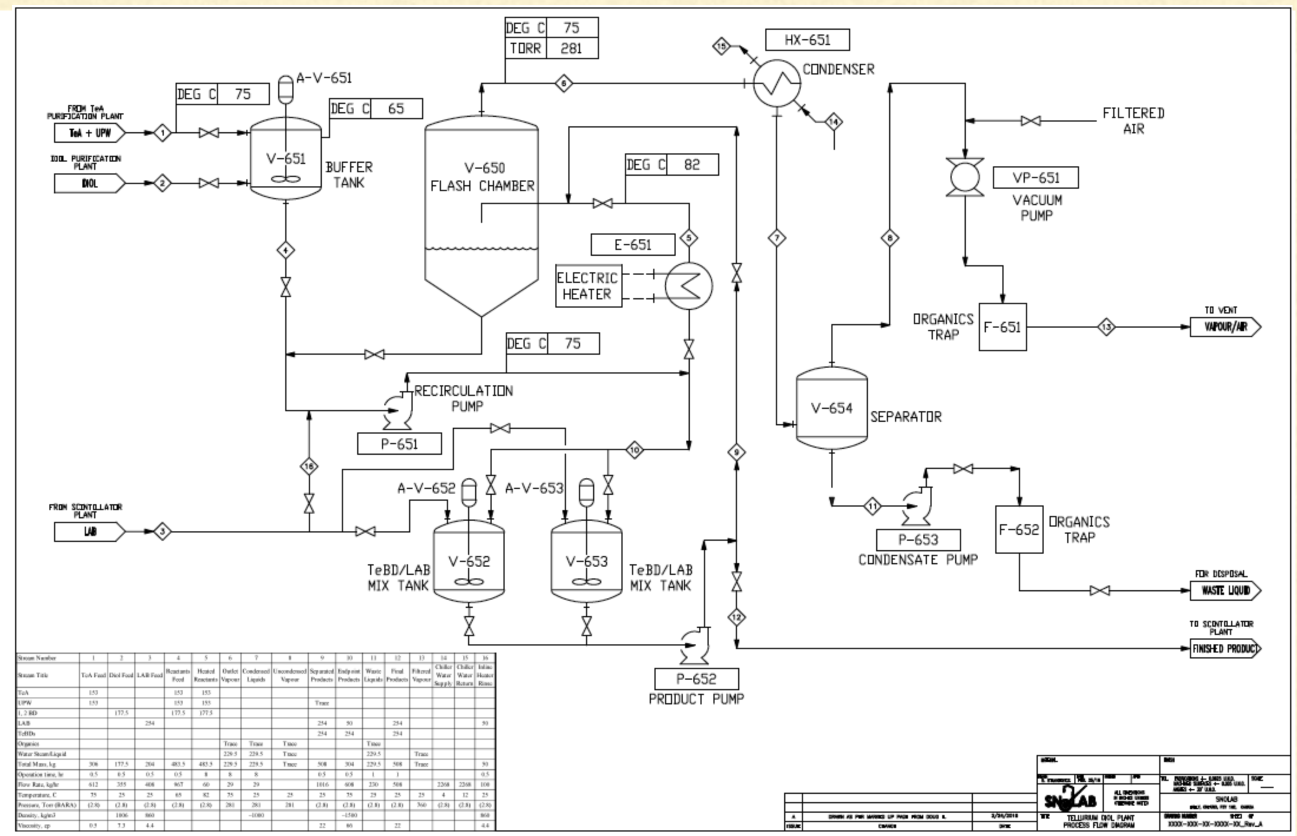



- investigated water-based approach (using surfactant)
  - 95% LS + 5% aqueous $Te(OH)_6$
  - *switched to new approach for loading*
- form Te organometallic complex using diols 

- dehydration reaction
  - mix telluric acid with butanediol
  - heat to drive off water

# SNO+ TE-DIOL SYNTHESIS PLANT



# SUMMARY

- There are several techniques for loading metals in organic liquid scintillator.
- Some techniques are general while others are quite specific.
- Many applications in neutrino physics (e.g. IBD antineutrino detection, neutron detection, calibration sources, double beta decay).