

# Gadolinium-loaded Liquid Scintillator For an Anti-Neutrino Detector

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# Current Reactor Safeguard

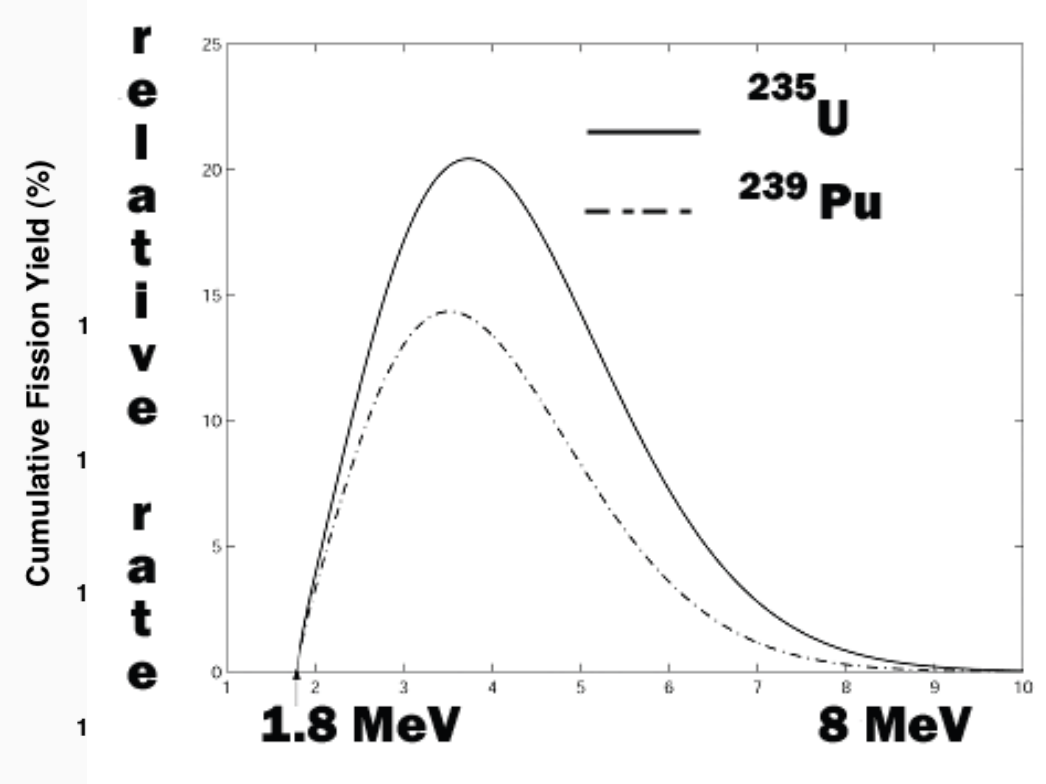
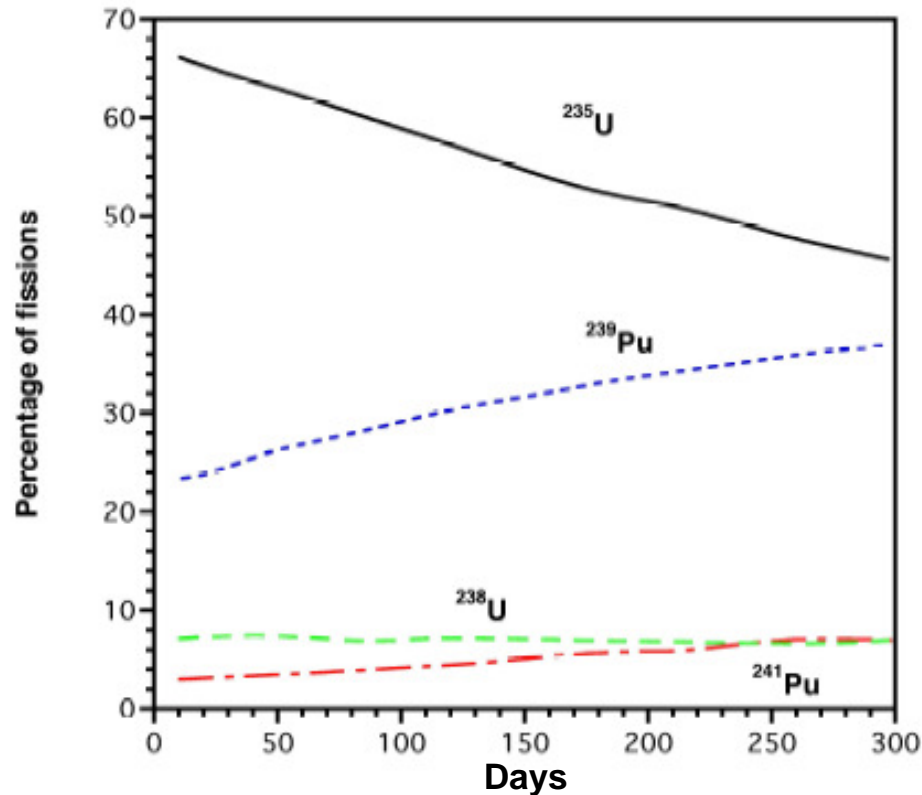
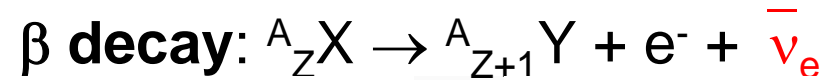
- IAEA aims to ensure peaceful development of nuclear energy.
- IAEA's safeguard regime is designed to detect diversion of fissile material (Pu, HEU) from civil nuclear fuel cycle facilities to military nuclear weapons programs.
- Current reactor safeguards practices rely heavily on containment and surveillance methods, as well as the physical presence of inspectors during refuelling activities at nuclear power plants:
  - No direct thermal power measurement is made
  - No direct Pu inventory measurement until reprocessing
  - Time consuming and costly to both IAEA inspector and reactor operator

# Anti-neutrino Detector: A new safeguard tool?

- Anti-neutrino detectors could provide continuous, non-intrusive, unattended measurements for safeguards regimes.
  - Reactors produce large amounts of anti-neutrinos which reveal fissile composition
  - Neutrino can not be shielded
  - Remotely monitor real-time reactor state
  - Neutrino interacts weakly → large detector, close to reactor
- IAEA has expressed strong interests in anti-neutrino detection for nuclear safeguard.

# Reactor Anti-neutrinos

Fission products are neutron rich nuclei:

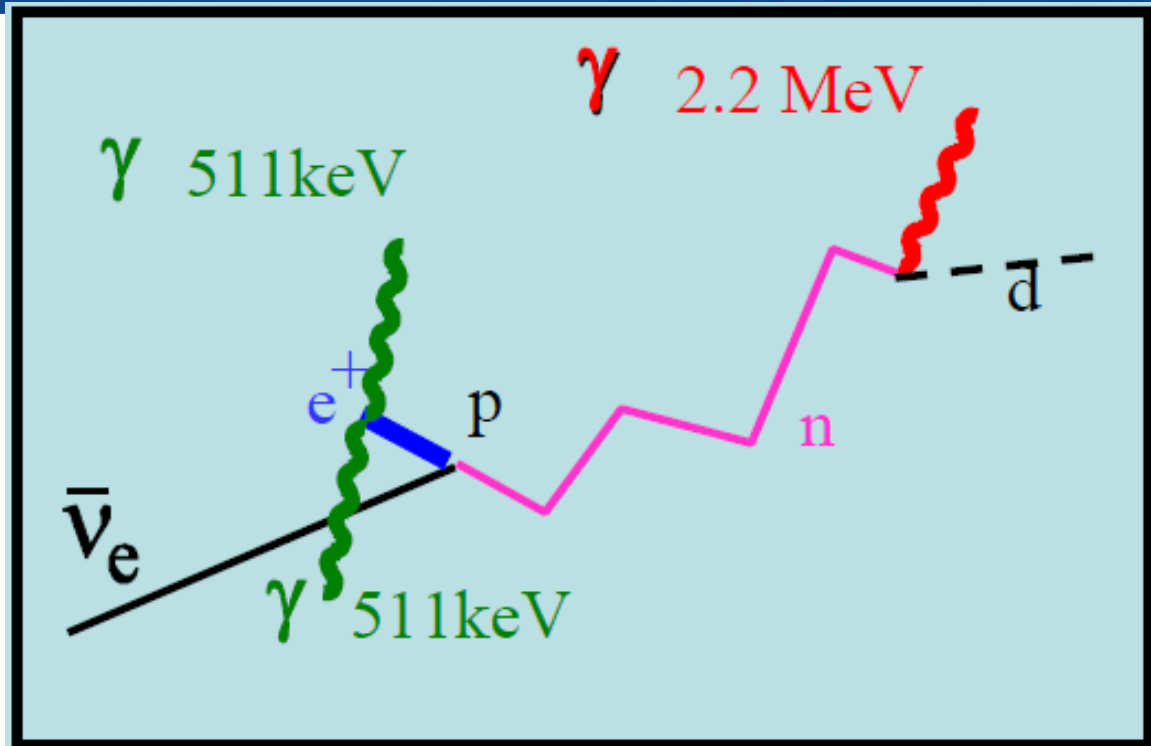
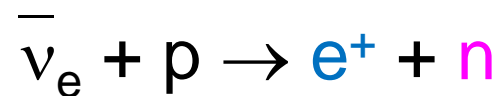


Anti-neutrino flux and energy spectrum are sensitive to the isotopic composition of the reactor core

- Short-term monitoring can measure reactor power
- Long-term monitoring can provide direct measurements of fissile inventory

# Neutrino Detection

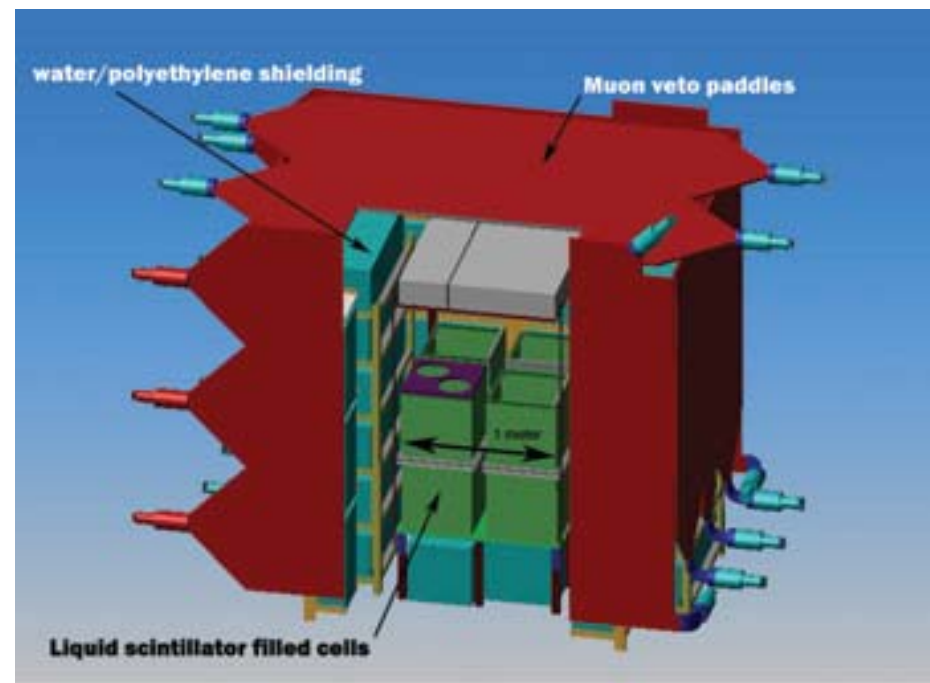
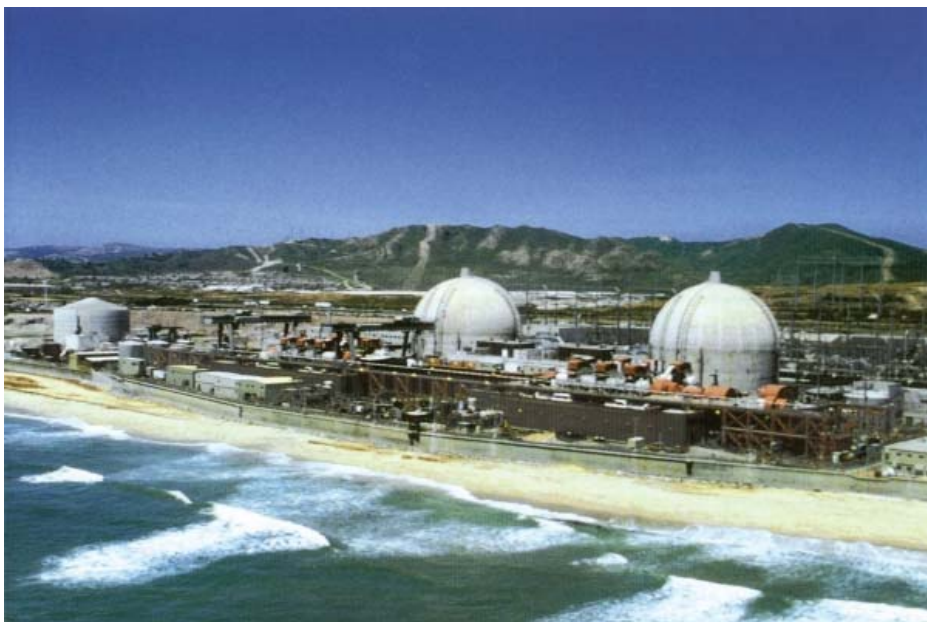
Inverse  $\beta$  decay:



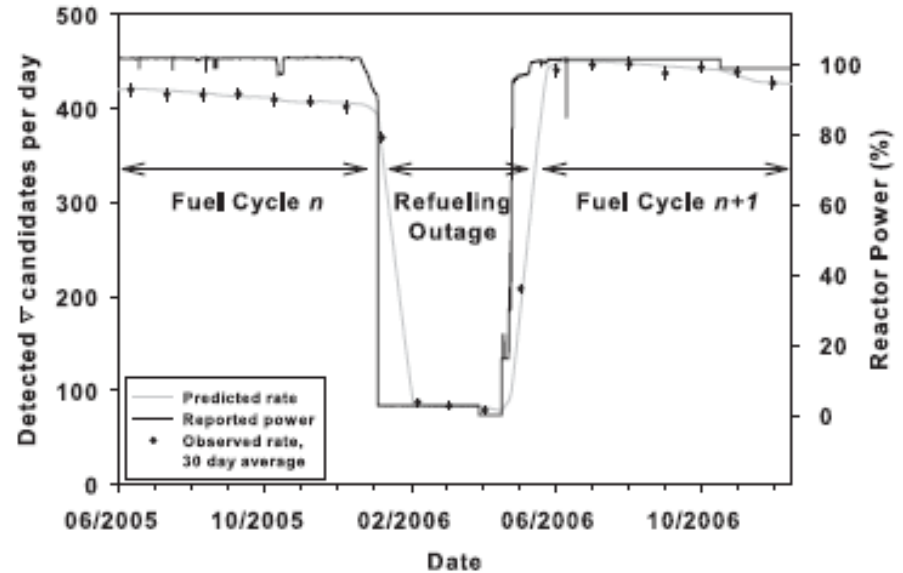
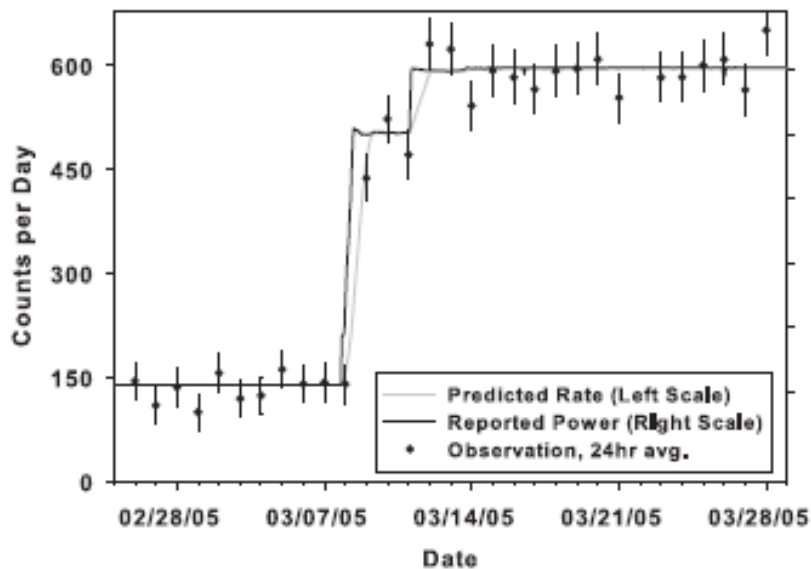
Coincidence of the prompt and delayed signals results in a distinctive signature for anti-neutrino detection

- **Prompt signal:**  $e^+$  annihilation  $\rightarrow E_\nu = E_{\text{prompt}} + \bar{E}_n + 0.8\text{MeV}$
- **Delayed signal:**  $n+p \rightarrow 180\mu\text{s}$  capture time, 2.2MeV  
 $n+\text{Gd} \rightarrow \sim 30\mu\text{s}$  capture time,  $\sim 8\text{MeV}$

# Prototype Deployment: San Onofre Nuclear Generating Station



# Prototype Deployment: SONGS detector results



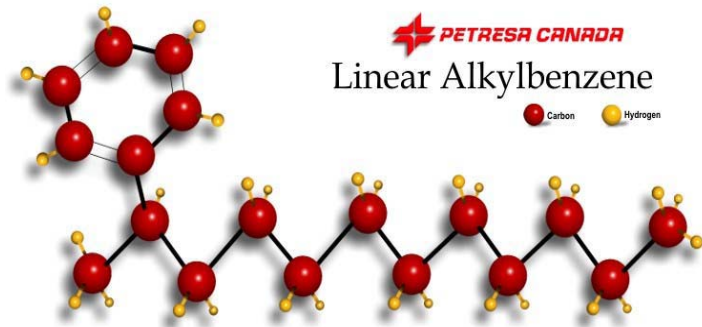
N. S. Bowden, Nucl. Instr. Meth. A 572 (2007) 985; J. Appl. Phys. 103, 074905 (2008)

☺ The SONGS detector successfully proved the anti-neutrino detection technology.

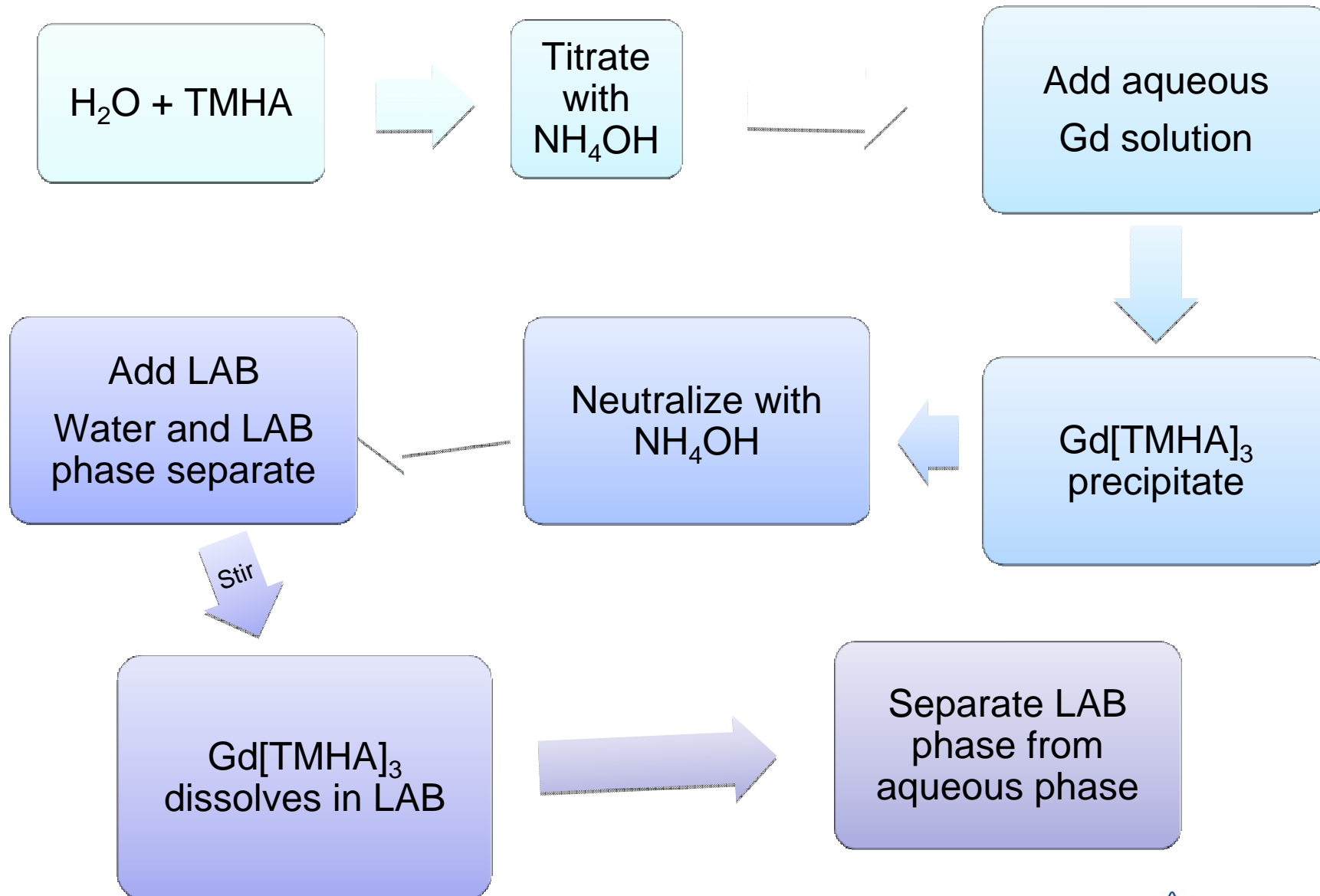
☹ Pseudocumene based Gd-LS is flammable and toxic, which raised some safety issues to the reactor operator.

# Linear Alkylbenzene (LAB)

- LAB is a commodity chemical used to make the surfactant in common, household detergents
- LAB has been chosen for SNO+ and Daya Bay neutrino experiments:
  - ✓ High light yield
  - ✓ Good optical transparency → long attenuation length
  - ✓ Long-term chemical and optical stability
  - ✓ Good chemical compatibility with detector materials (e.g. acrylic)
  - ✓ Safe: high flash point and low toxicity
  - ✓ Available and affordable



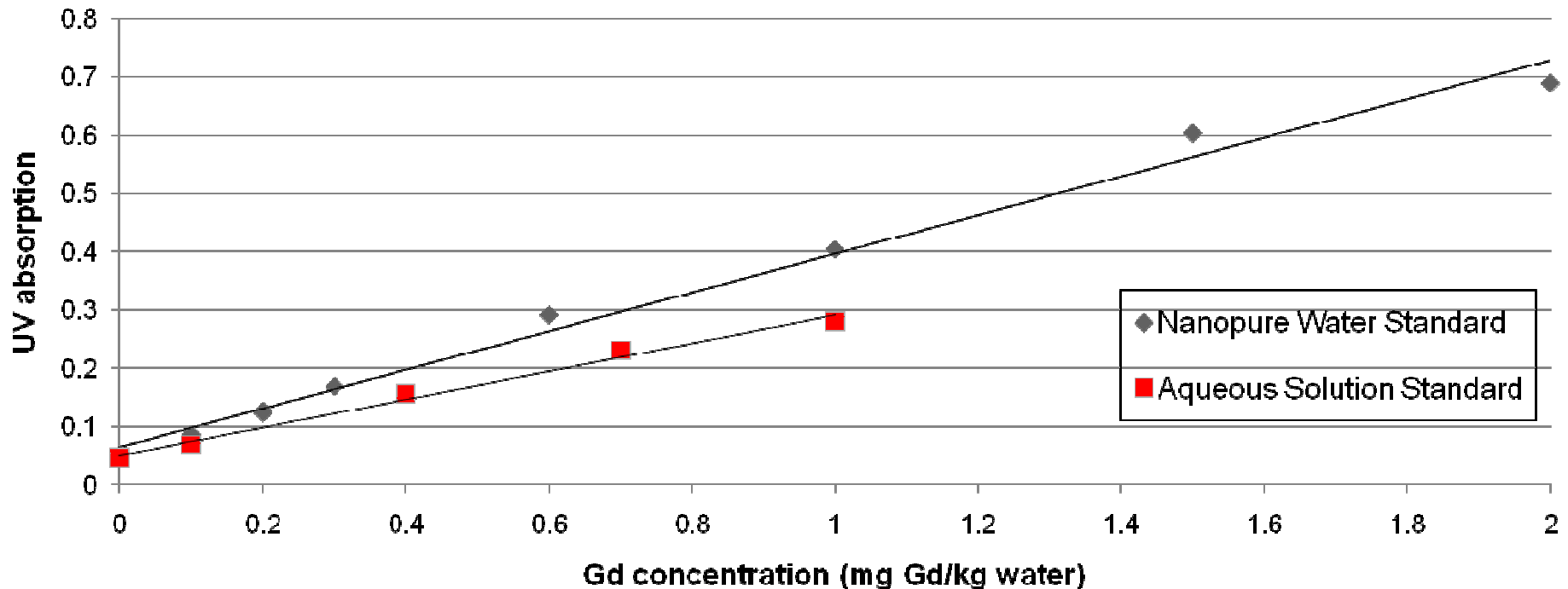
# Synthesis of 2% Gd-LAB



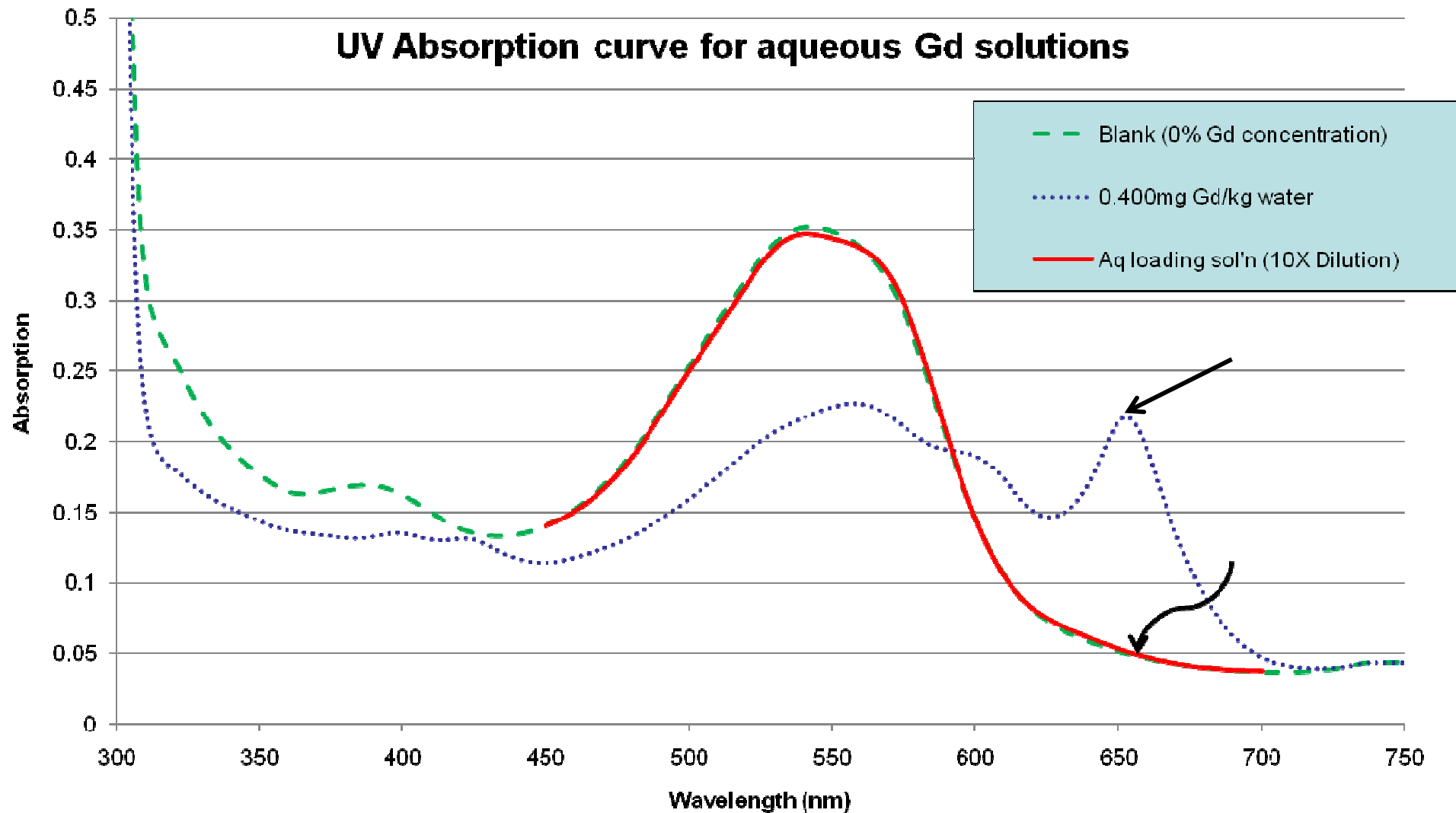
# Spectrophotometric Analysis of Gd Concentration

- Gd concentration in aqueous phase was measured.
- Spectrophotometric analysis of Gd-Arsenazo III complex at 655nm.
- Gd concentration in organic phase was calculated based on mass balance.

Gd concentration vs. UV Absorption

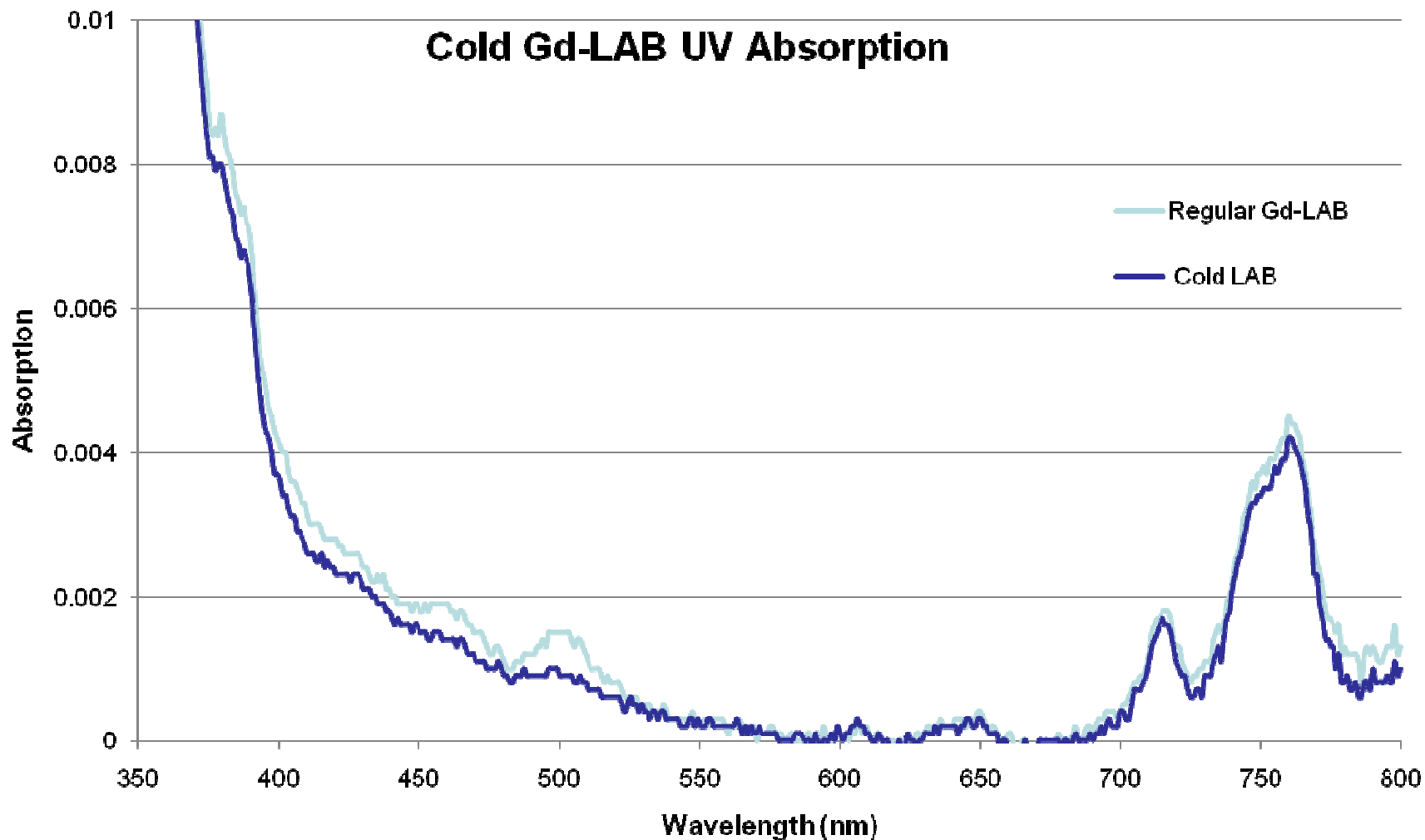


# Spectrophotometric Analysis of Gd Concentration

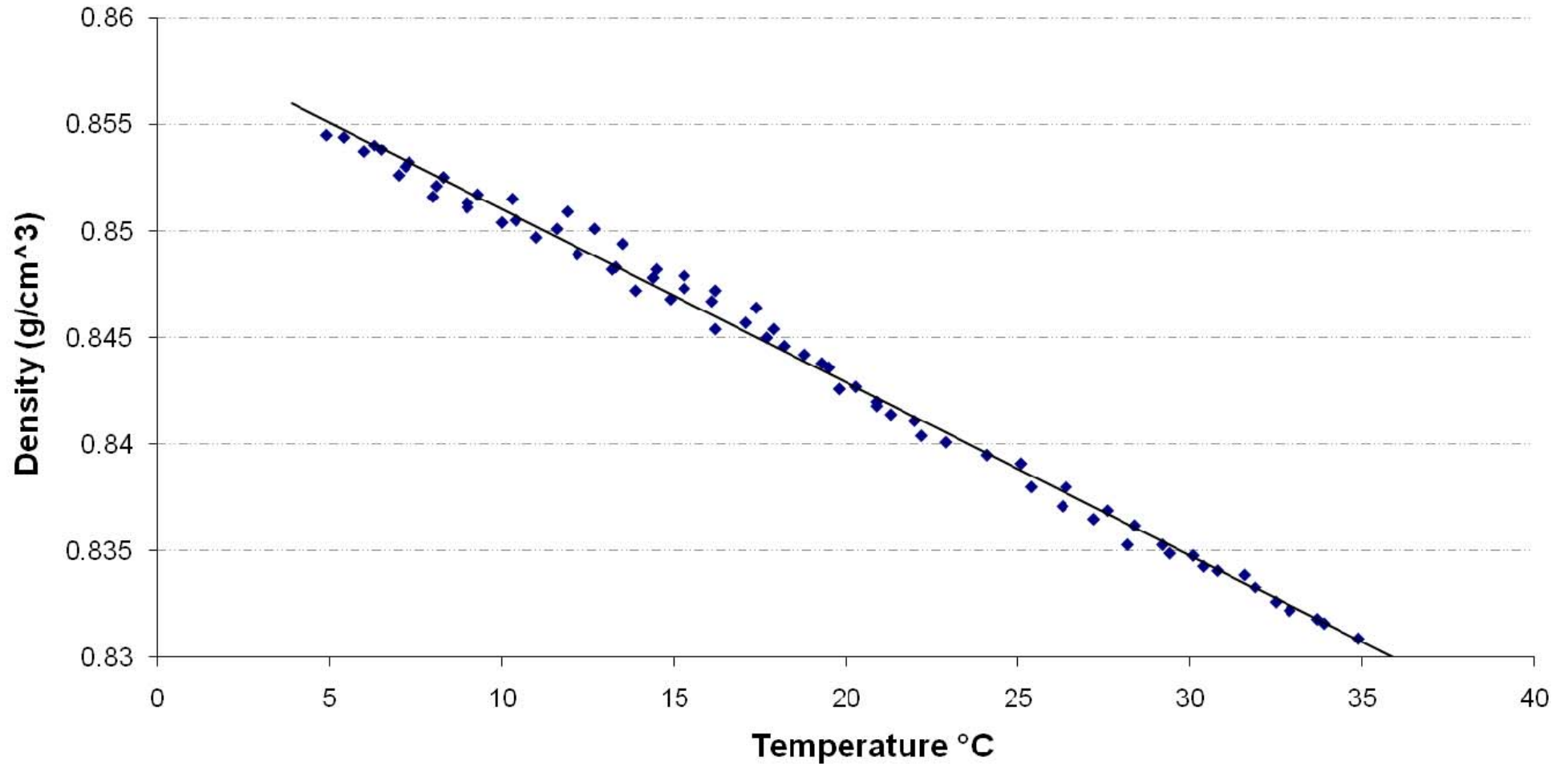


**>99% of Gd loading efficiency to LAB**

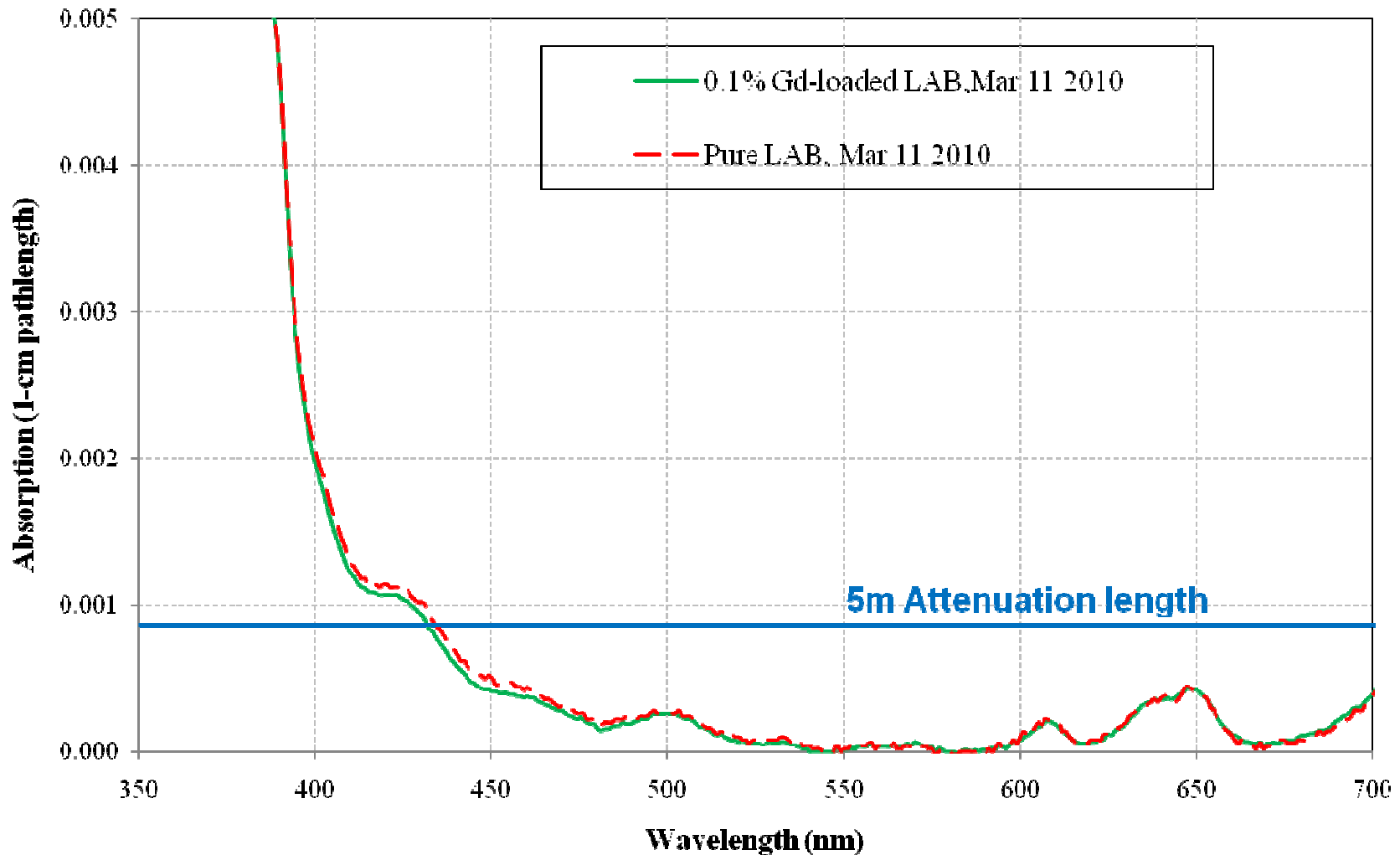
# Gd-LAB Characterization: Exposure to Cold Temperature



# Gd-LAB Characterization: LAB Density Change with Temperature

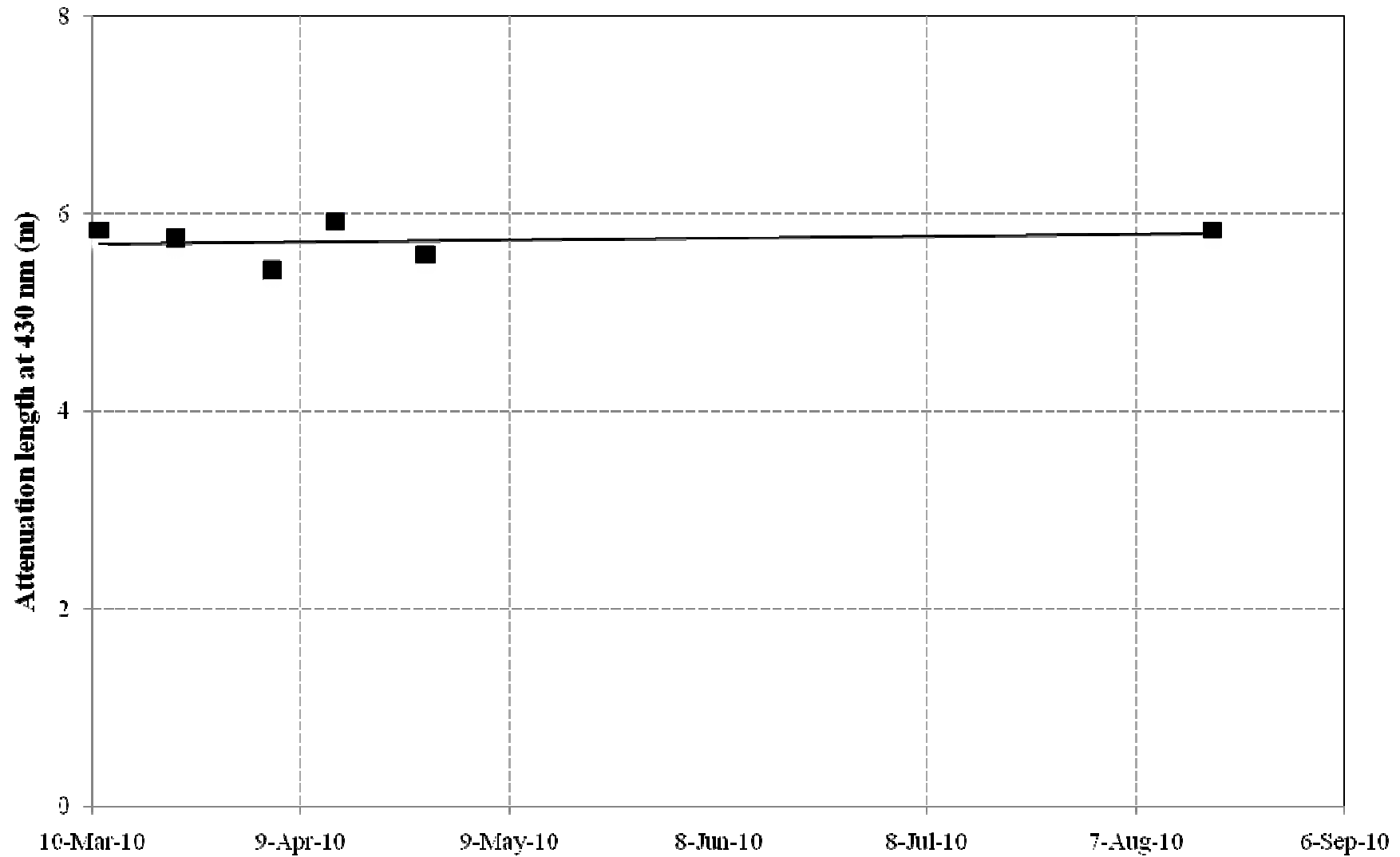


# Gd-LAB Characterization: Attenuation length



5.7±0.3 m of attenuation length at 430nm

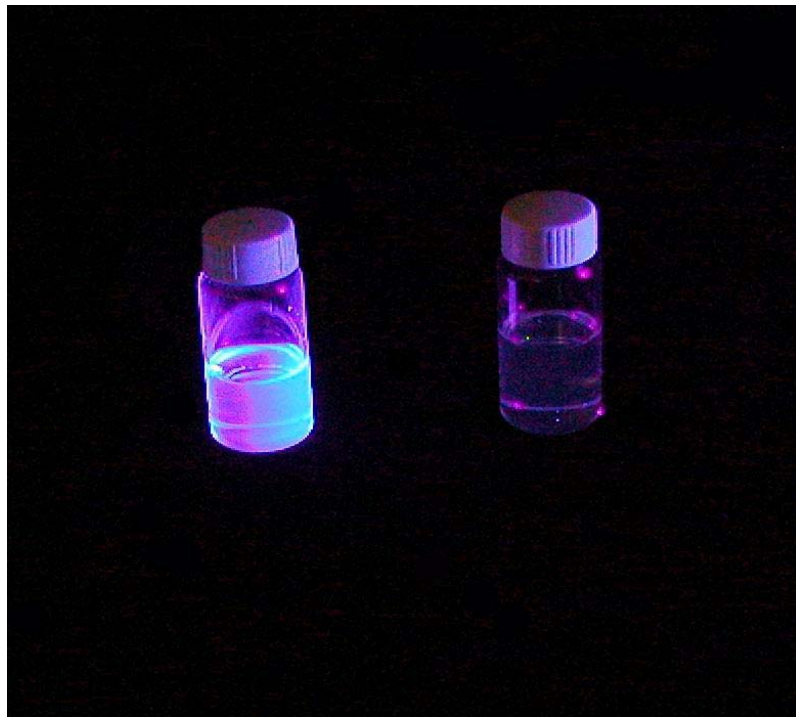
# Gd-LAB Characterization: Long-term Stability



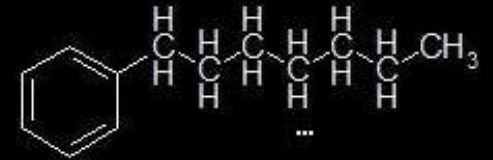
# Preparation of 0.1% Gd-LS

## Final Gd-LS:

- **0.1 w/w% Gd:** from 2% Gd-LAB
- **3 g/L PPO:** from 9% w/v PPO in LAB
- **5 mg/L bis-MSB:** from 450 mg/L bis-MSB in LAB



**LAB** ( $C_{16-19}H_{26-32}$ )

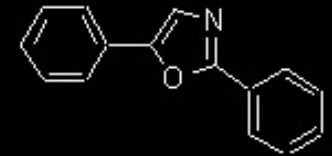


Density: 863 g/L

Flash point: 140°C

High transparency, high light yield

**PPO** ( $C_{15}H_{11}NO$ )



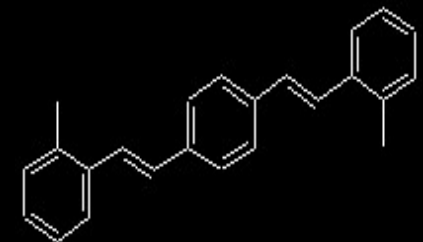
Primary fluor

Absorption band: 280-325nm

Emission band: 350-400nm

Solubility : >10 w/v% in LAB

**Bis-MSB** ( $C_{24}H_{22}$ )



Wavelength shifter

Absorption: 320-370nm

Emission band: 380-450nm

Solubility: >500 mg/L in LAB

# Summary

- A LAB-based Gd-LS is synthesized for nuclear reactor safeguards and monitoring by anti-neutrino detectors.
- Initial characterization tests are promising: good long-term stability and acceptable light transparency etc.
- More chemical and optical characterization tests are ongoing and will be reported in the near future.

# Merci

 **AECL EACL**

