LIGHT ATTENUTION LENGTH MEASUREMENT FOR WATER-BASED NEUTRONS AND NEUTRINOS DETECTORS

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Outline

- Introduction: Detecting antineutrinos
- Improving Neutron Detection with Gadolinium
- Application in Fundamental Science & Nuclear Security
- Gd-doped Detectors: Challenges
- The LLNL Setup
- Conclusion

Antineutrino Detection

The basis for Water-Based detectors is the detection of Cerenkov light resulting from the antineutrinos interactions with protons in the water:

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

The antineutrino interaction with a proton produces:

1. **A positron** which absorbs most of the antineutrino energy, producing Cerenkov light. Above the Cerenkov threshold ($v>c/n$), the number of emitted photons is nearly proportional to the energy.

2. **A neutron** that wanders through the water, thermalizes and is eventually captured by a proton releasing in the process a 2.2 MeV gamma-ray creating Compton electrons. The capture time is ~ 200 microseconds.

   - The Cerenkov threshold for Compton electrons in water is ~0.263 MeV. **The 2.2 MeV gamma energy is usually spread over several Compton electrons, resulting to only a few amount of light being detected per neutron capture.**

Neutrino detection can be enhanced by doping the water with a neutron capture agent like gadolinium and requiring a coincidence signal of Cerenkov light from positron and light produced from gamma cascade due to the neutron capture.

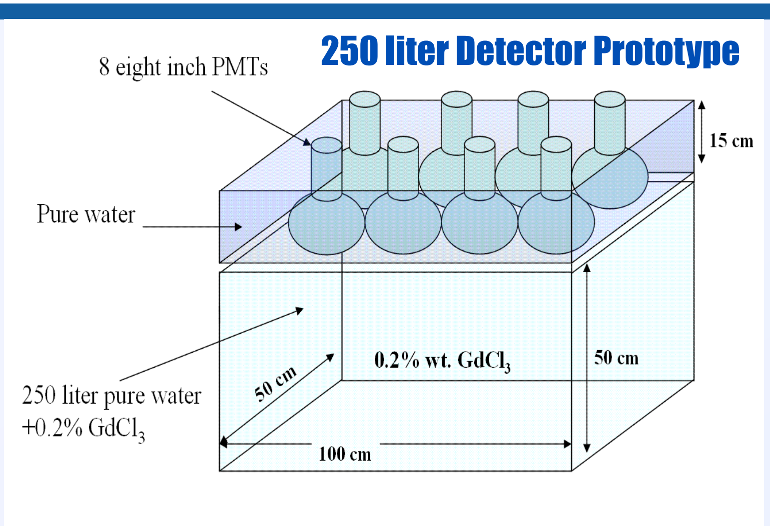
Improved neutron detection With Gadolinium Compounds

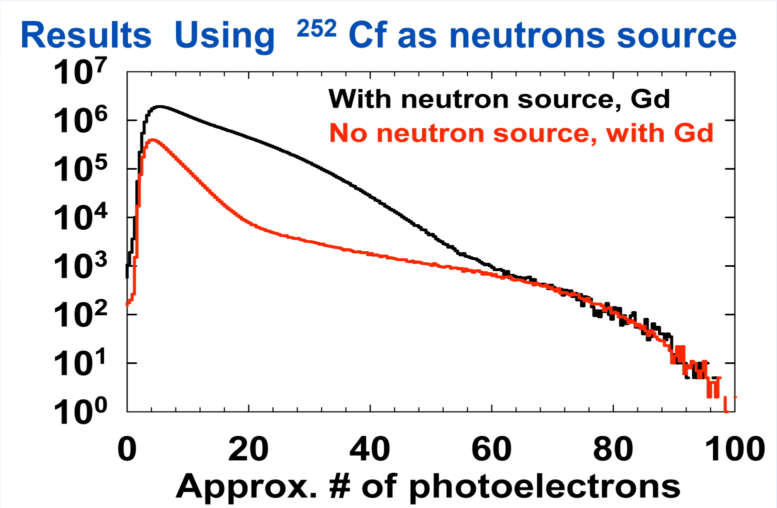
Use Gd to detect the neutron, as in liquid scintillator

Gd-doped water (Bernstein, 1999)

GdCl3 (Beacom& Vagins, 2003)

- Higher Capture Cross Section: 49,000 barns (compared to 0.2 barns for proton)
- **n+Gd →~8MeV** γ: The signature of the Gd capture is an 8 Mev Gamma cascade easily detectable. (compared to 2.2 MeV for proton)
- Shorter Capture time interval: ~30 μsec 0.1% Gadolinium, (compared to 200 μsec)



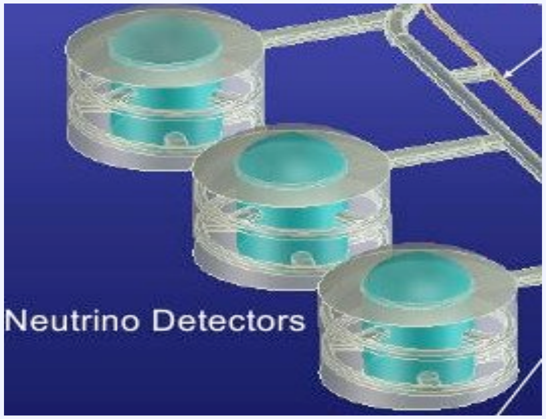


S. Dazley et al, **http://arxiv.org/abs/0808.0219**

Motivation For Neutron Detection

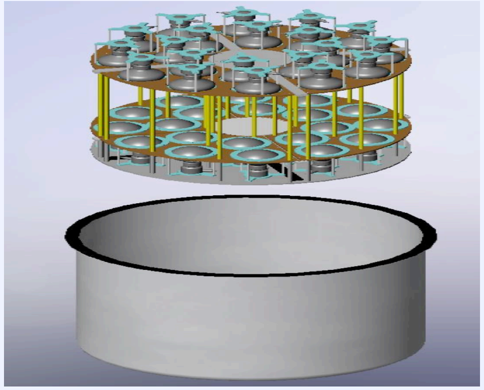
Possible Uses in Fundamental Science: LBNE

The goals of the experiment include:



- ❑ **Neutrino Physics**
- •Mixing Angle
- • Mass Hierarchy
- •CP Violation
- ❑ **Nucleon decay**
- •Proton Decay
- ❑ **Neutrino Astrophysics**
- •Galactic Supernovae
- •Relic Neutrinos

Possible Nuclear Security Uses: 4-ton Gd-doped Water Detector at LLNL



Goal: development of very large "car wash" style neutron detectors for cargo screening.

Gd-doped neutron/antineutrino detectors –research questions

Known

•Gd cost -relatively inexpensive

•Gd availability. plenty of it in several places worldwide.

•Gd quantity -0.1% sufficient for 85% capture.

•Gd capture signature (8 MeV γ-cascade) -tens of p.e. predicted.

To be studied

•Can we see the relatively weak neutron signal, time coincidence, and actual antineutrino signals in Gd-water? **Remarkably, not done until recently**

•What are the effects of Gd compounds on detector components and on attenuation?

•What is the attenuation of light in Gd-doped water?

•Question from LBNE detector calibration – how accurately can attenuation be measured?

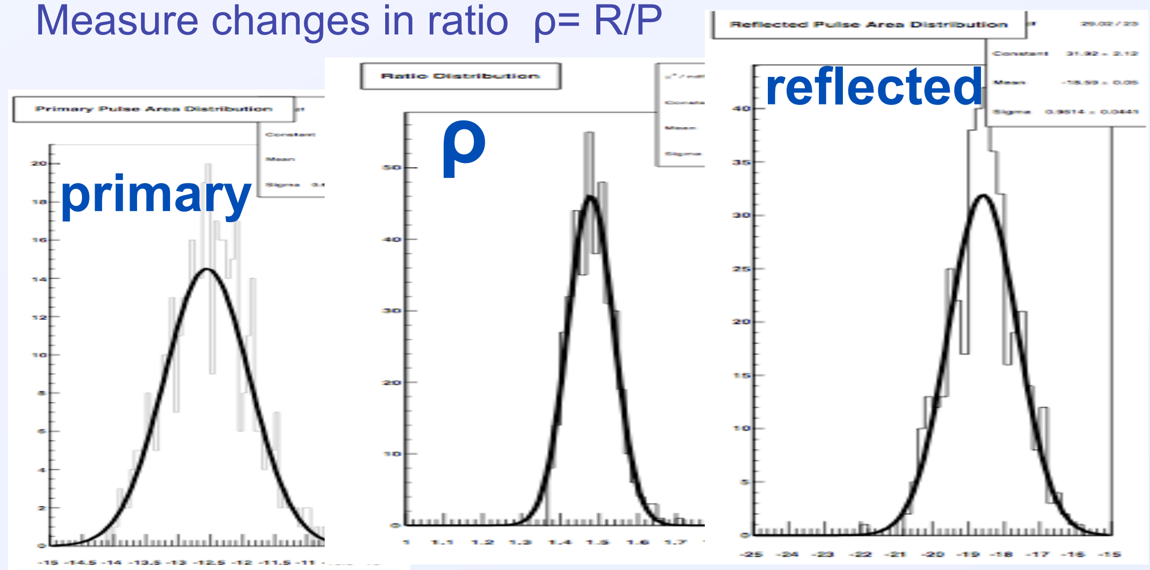
Water Transparency Measurement: Current Work

Method:

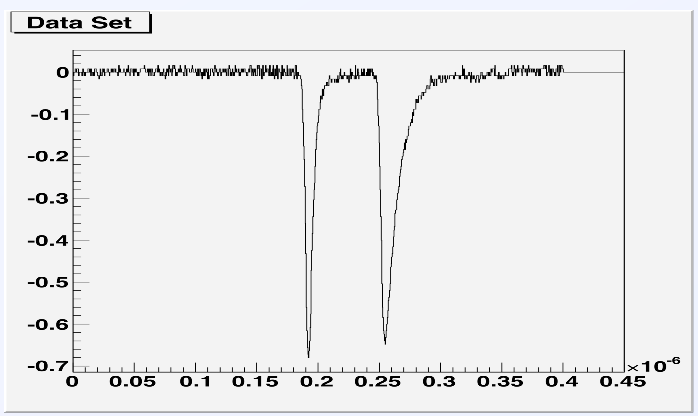
Laser beam intensity is measured before and after transmission through attenuation arm filled with water sample.

Both primary (P) and Reflected (R) beam intensities are measured with same PMT.

Measure changes in ratio $\rho = R/P$

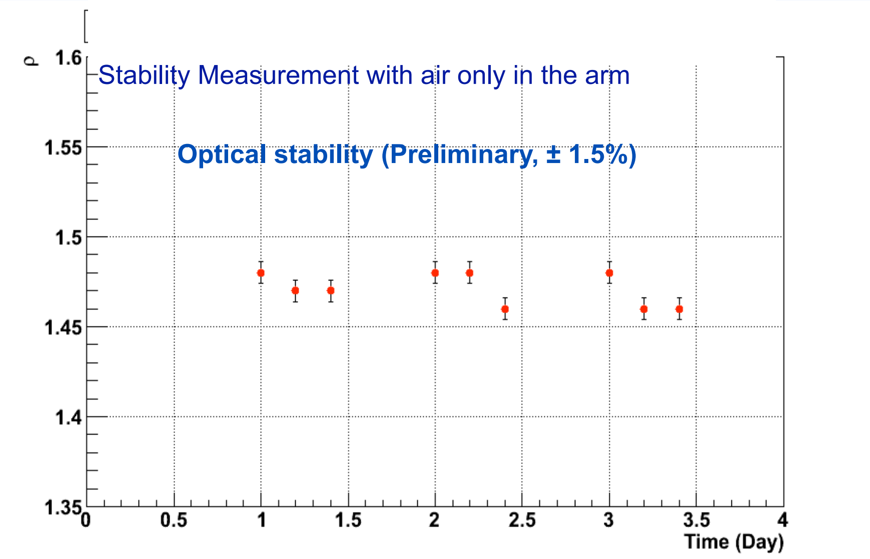


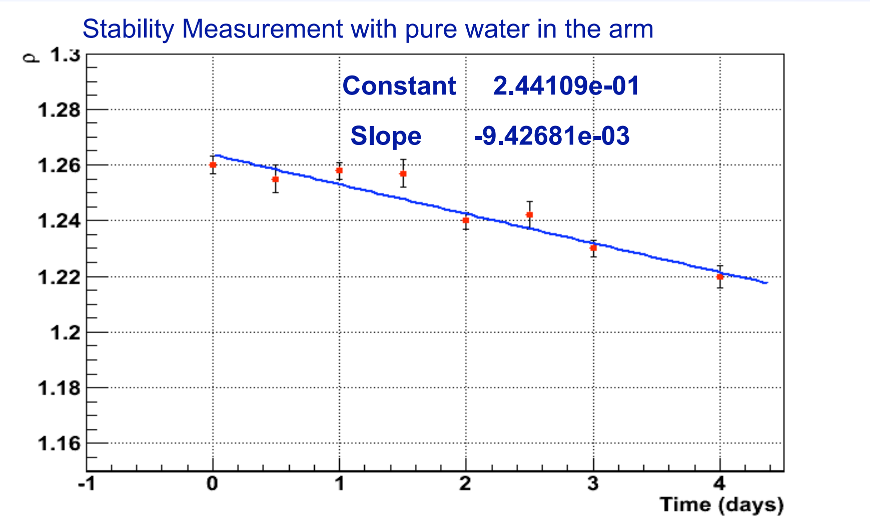
Typical Waveform for 337 nm



An experimental data point is the average value of the ratio taken over 500 waveforms.

Water Transparency Measurement: Current Work





With air only in the transmission arm, we determined that the variation in the ratio is about 1.5%.

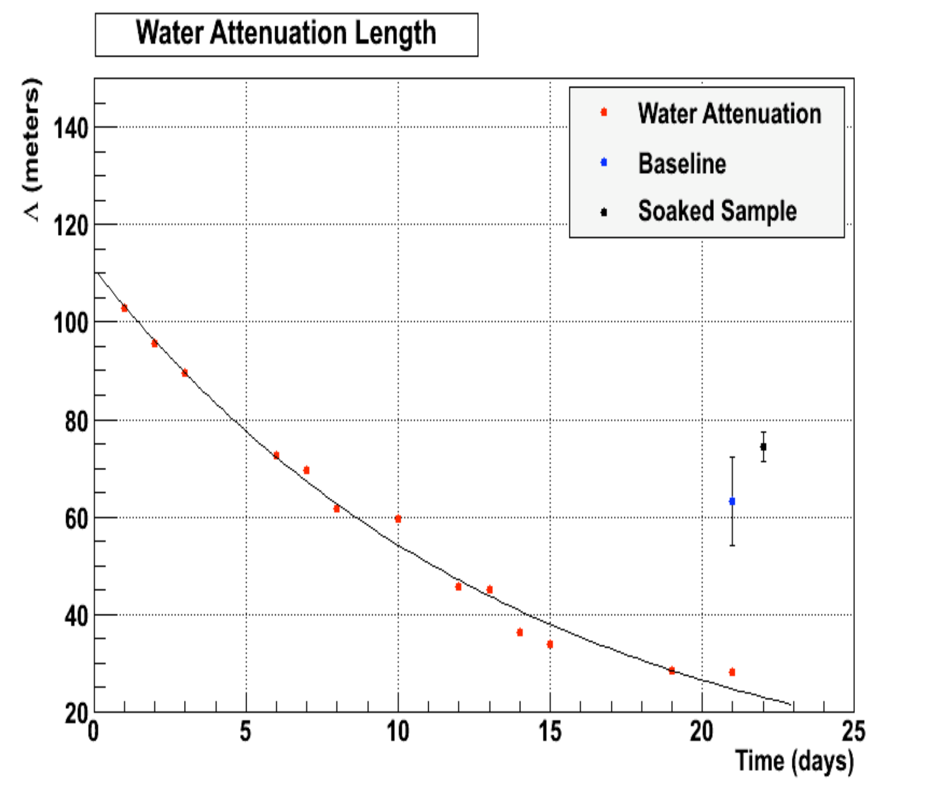
When water is in the arm, the ratio is a measure of the water transparency: **observed a degradation in the ratio at a rate of 1% per day.**

The probable cause of the degradation is chemical materials leaching into the water as a result of the permanent contact of the water with the plastic.

Water Transparency Measurement: Current Work

The attenuation length is obtained from measuring the water transparency with two separate transmission arms, **a long (8-meters) a short arm (~12.5 cm) and using the equation**:

$$\Lambda^{-1} = 1/(L_L - L_S) \times \ln(\rho_S/\rho_L)$$



Light Attenuation Length Measurement in pure Water

Two Experiments were performed:

1. **An experiment to determine the precision with which we can measure the attenuation length of pure water.**
2. **An experiment to determine the effect of a 6"x5" HDPE plastic material on the quality of the water. Two tests were performed:**

PRELIMINARY RESULTS

1. **An exponential fit of the daily measurements data indicates:**
    1. **Some degradation every day – fits an exponential**
    2. **4%** experimental uncertainty (residuals from exponential)

2. **After 21 days the attenuation length of the baseline was measured at 62+/- 9 meters.**

    •The uncertainty for the baseline water was determined by measuring the degradation rate of 6 "identical" drums filled with pure water and left at rest for 28 days.

    •The result indicates a degradation rate that varies by up to 25% from drum to drum.

    • Develop a table to check att. Length of the soaked sample against the null hypothesis which is the expected attenuation length when no material is soaked in the drum.

3. **After 21 days the attenuation of the soak water was measured at:74+/- 3 meters.**

Conf. Level	% loss	Time (days)
1σ	15%	5.4
2σ	30%	12
3σ	45%	20
90%	91%	80

Conclusion

We have developed a precise instrument to measure light attenuation in pure water (~18 mega-Ohms).

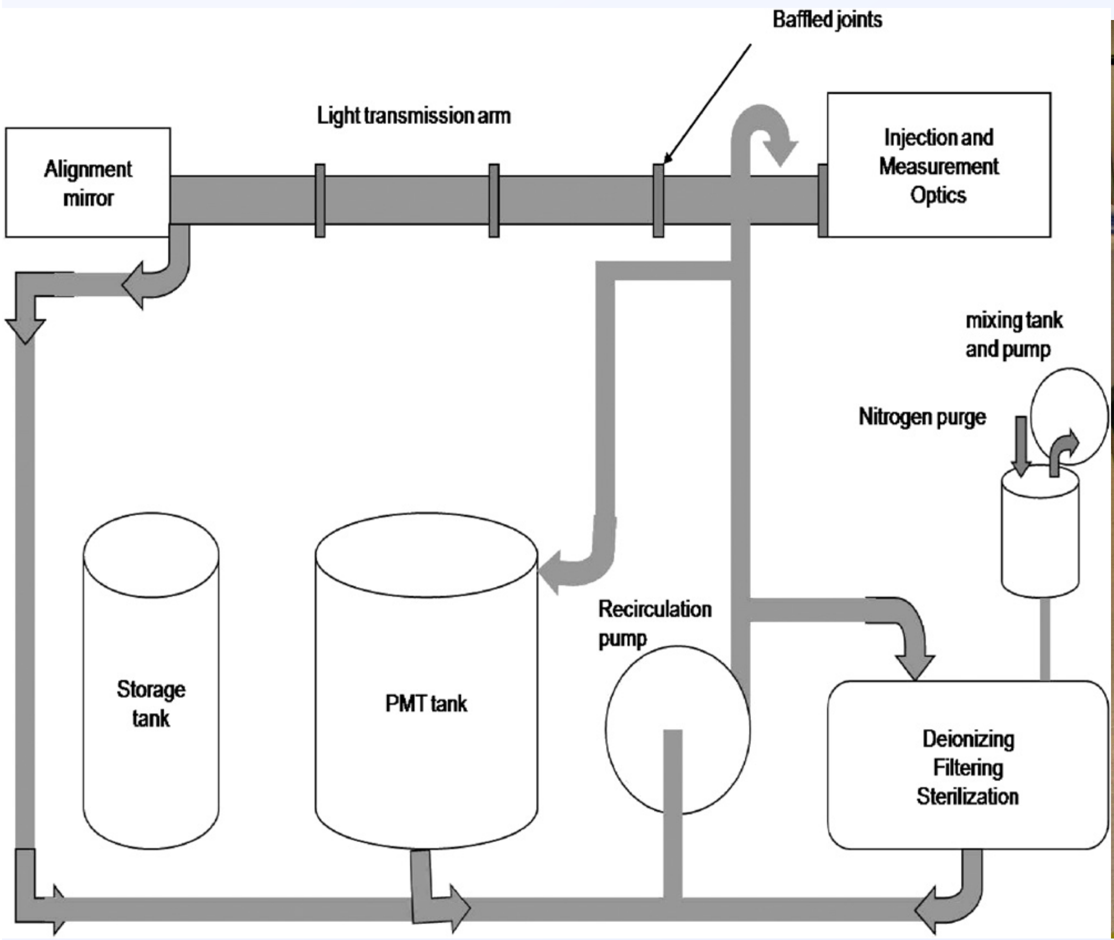
- Attenuation length in pure water was measured to within 4%.
- The Degradation rate of pure water left at rest in the polypropylene drums varies by up to 25%. This variation is actively under investigation.
- Attenuation length of soaked water is consistent with null hypothesis at the 3σ level.
- Similar studies with Gadolinium-doped water and others materials are in the plans

Thank you.

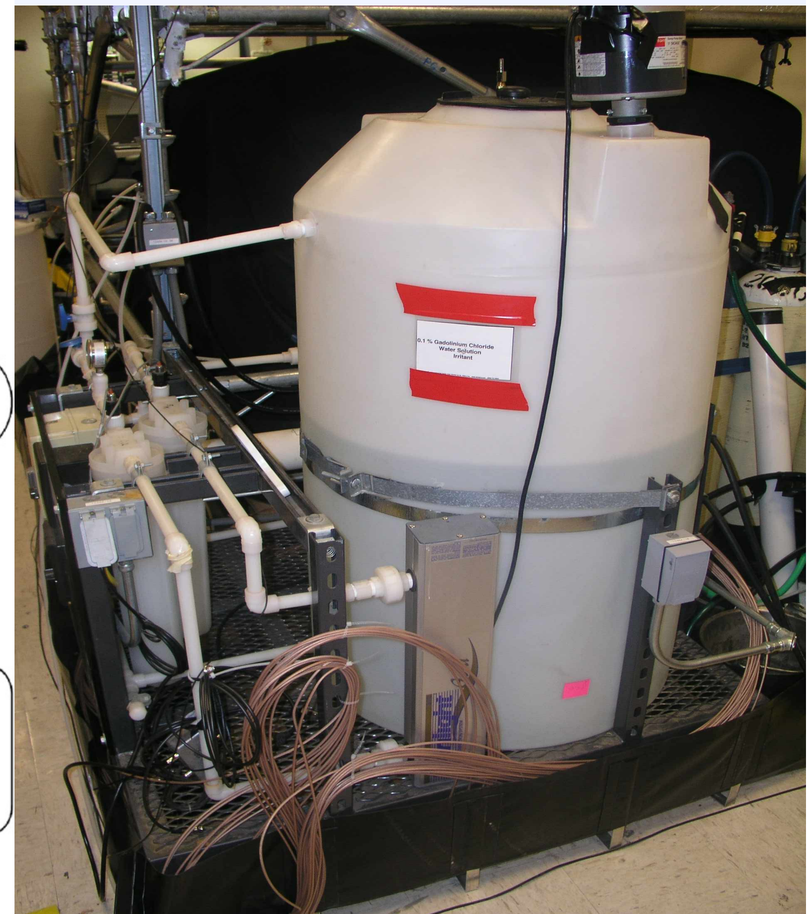
Backup Slides

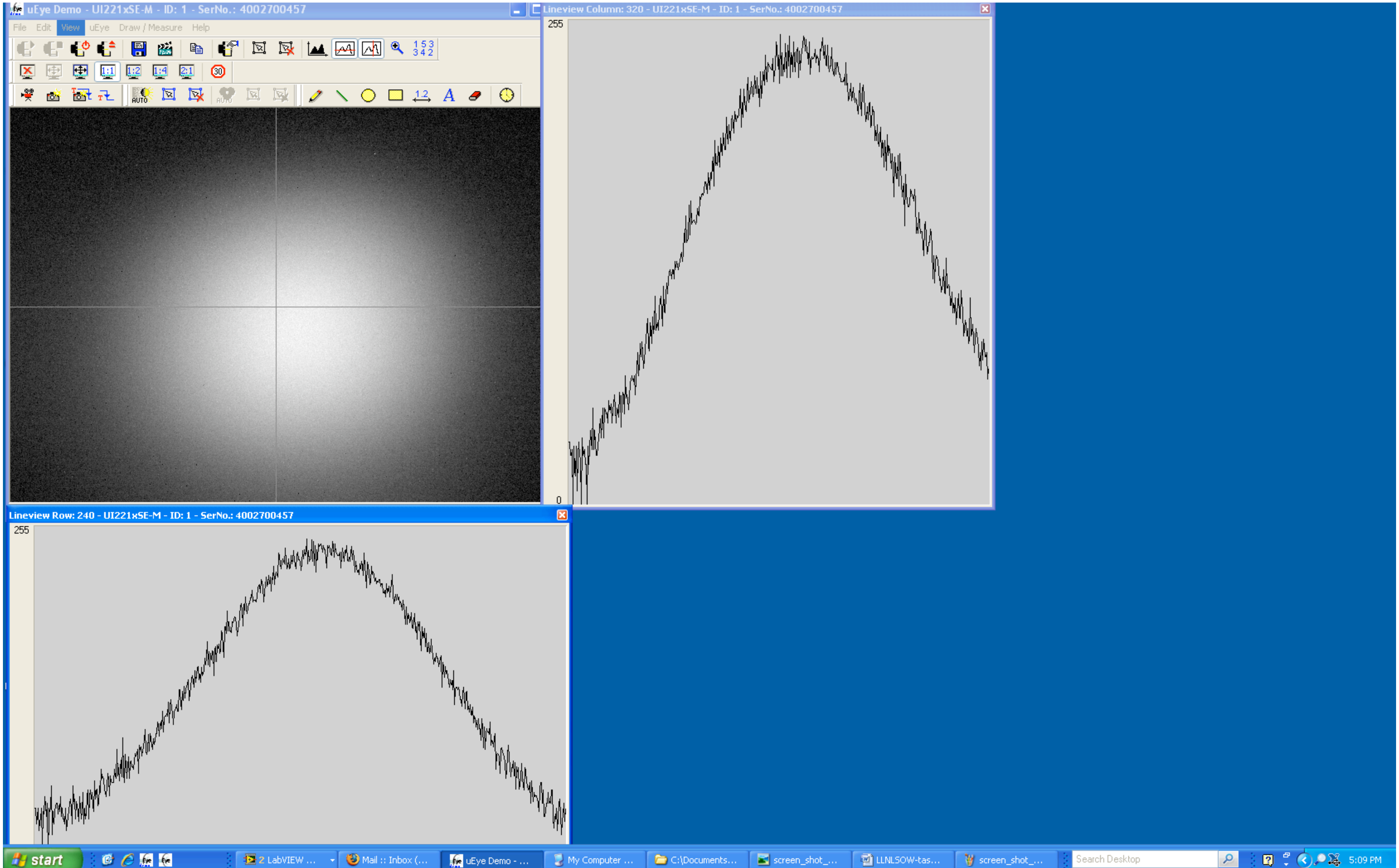
Gadolinium Doping R&D Issues

- Attenuation Arm Optics



Water Processing equipment

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