LANL nEDM Collaboration

Los Alamos National Laboratory

C.-Y. Liu, J. Long, W. Snow
Indiana University

B. Plaster
University of Kentucky

S. K. Lamoreaux
Yale University

E. Sharapov
Joint Institute of Nuclear Research
Outline

• Introduction/overview
• LANL UCN Source
• LANL UCN Source upgrade
• UCN transport system
• HV R&D
• 199Hg comagnetometer R&D
• Magnetics
• UCN detection/spin analysis
• Summary
Concept for nEDM experiment at LANL

• A neutron EDM experiment with a sensitivity of $\delta d_n \sim O(10^{-27})$ e-cm based on already proven room temperature Ramsey’s separated oscillatory field method could take advantage of the existing LANL SD$_2$ UCN source
  – nEDM measurement technology for $\delta d_n \sim O(10^{-27})$ e-cm exists. What is holding up the progress is the lack of UCN density.
  – The LANL UCN source currently provides a UCN density of $\sim 60$ UCN/cc at the exit of the biological shield
  – A 5-10 fold improvement in the delivered UCN density is required for an nEDM experiment with $\delta d_n \sim O(10^{-27})$ e-cm

• Such an experiment could provide a venue for the US nEDM community to obtain physics results, albeit less sensitive, in a shorter time scale with much less cost while development for the SNS nEDM experiment continues.
Goals for the 3 year LDRD project (LDRD: LANL internal funding)

• Demonstrate that such an nEDM experiment is indeed possible (i.e. statistical sensitivity)
  - Upgrade the existing LANL SD$_2$ based UCN source
  - Demonstrate that a sufficient number of UCNs can be stored in a realistic nEDM cell prototype

• Realistic: HV, UCN storage, 199Hg comagnetometer, UCN spin polarizer, UCN spin analyzer, etc
  Perform Ramsey’s separated oscillatory field measurements to demonstrate the statistical sensitivity per measurement or per day

• Addressing systematic effects due to magnetic field non-uniformity is beyond the scope of this phase of the project
Los Alamos Neutron Science Center (LANSCE)

LANSCE Accelerator
(800 MeV, 1 mA)

Lujan Center

UCN experimental area
LANL UCN Experimental Area
LANL UCN Experimental Area

UCNA experiment

UCNτ
LANL UCN Source

Science program at LANL UCN Source

- UCNA experiment
- UCNB experiment
- UCN\(\tau\) experiment
- Actinide science
- Detector R&D for the Nab experiment at SNS
- Neutron storage R&D for the SNS nEDM experiment
LANL UCN Source performance

Unpolarized UCN density at the exit of biological shield
Area B Layout
Area B Layout
nEDM area preparation
Current LANL UCN Source

Graphite

Solid deuterium

Beryllium

Polyethylene beads

W target
Source optimization

\[ \rho = \frac{p \ I \ V_{SD2} \ \tau}{V_{tot}} \]

\( \rho \): UCN density in the experiment (UCN/cc)
\( p \): UCN production density (UCN/cc/\( \mu \)C)
\( I \): proton beam current (\( \mu \)A)
\( V_{SD2} \): SD2 volume (cc)
\( V_{tot} \): total volume (cc)
\( \tau \): UCN lifetime (effective lifetime because of the shutter operation) (s)
The goals of the UCN source optimization and boundary conditions

This source upgrade is based on the experience gained by working on the previous prototype and the current source.

• Goals: maximize the UCN production
  • More optimized geometry (e.g. diameter and connection to the horizontal guide)
  • More optimized cold moderator
  • Ease of engineering

• Boundary conditions
  • The “source insert” can be replaced
  • The Be box and graphite moderators cannot be modified
Current and new sources (MCNP model)

Current

Concrete

Graphite

Rep

SD$_2$

Be

Cold moderator (polyethylene)

New

Concrete

Graphite

Cold moderator
Current and new sources (bottom part)

Current

Graphite

SD₂

Be

Cold moderator (polyethylene)

New

Graphite

SD₂

Be

Cold moderator
Current and new sources (top part)
Tools used

• MCNP6:
  • To calculate the cold neutron flux in the SD2 volume
  • Started from 800 MeV proton producing spallation neutrons
• Additional $S(\alpha, \beta)$ files

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperatures</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ortho SD2</td>
<td>5K</td>
<td>R. Granada</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>5K, 77K, 293K</td>
<td>C. Lavelle</td>
</tr>
<tr>
<td>Solid methane</td>
<td>20K</td>
<td>D. Baxter</td>
</tr>
</tbody>
</table>
UCN production cross section

• UCN production cross section taken from Atchison et al. (2007) and Frei et al. (2010).

\[ P_{UCN} = \int \Phi_{CN} \sigma_{UCN} dE \]

7 meV ~ 80 K

• UCN production rate is given by

Atchison et al (2007)

Frei et al (2010)
Simulation of the current UCN source

Cold neutron flux in the SD$_2$ volume (in the top 2.5 cm)

<table>
<thead>
<tr>
<th>Moderator</th>
<th>UCN production (UCN/cc/μC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly 77K</td>
<td>232</td>
</tr>
<tr>
<td>Poly 293 K</td>
<td>183</td>
</tr>
</tbody>
</table>

The source performance data indicate UCN production rate of ~100 UCN/cc/μC
Source radius vs UCN production

Production vs. Source Radius

![Graph showing the relationship between source radius and UCN production.](image-url)
Comparison of cold moderators

Cold neutron flux in the SD$_2$ volume (in the top 2.5 cm)

- Cold moderator = polyethylene at 45 K
- Cold moderator = solid methane at 20 K
- Cold moderator = liquid methane at 100 K

Other cold moderator materials considered include: LH$_2$ and mesityline
Engineering considerations

- Heat to the cold moderator ~ 50 W

<table>
<thead>
<tr>
<th>Source</th>
<th>Heating (W)</th>
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<tbody>
<tr>
<td>Beam</td>
<td></td>
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<tr>
<td>Moderator</td>
<td>25</td>
</tr>
<tr>
<td>Container wall</td>
<td>10</td>
</tr>
<tr>
<td>IR</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
</tr>
</tbody>
</table>

- Radiation damage:
  - Methane produces hydrogen gas as well as tar like substances
  - Heating and other engineering consideration lead to use of polyethylene beads
  - Need improved cooling method
UCN production as a function of the distance from the bottom of the SD2 volume

Cold moderator = polyethylene 77K
Additional thermal moderator and UCN production

- UCN prod: 1.00
- Graphite
- Beryllium

- Graphite: 0.91
- Beryllium: 0.87
- Graphite: 0.75
- Beryllium: 0.60
Area B Layout
UCN transport simulation: Geometry and Parameters

Old Source Diameter 7.87”
New Source Diameter 5.76”

\[ \left( \frac{D(\text{Old})}{D(\text{New})} \right)^2 = 1.87 \]

Simple model for wall interactions in the guides:
• Loss per bounce 3e-4 (independent of energy)
• Non-specularity 3%
• \( V_f(\text{guides}) = 184 \text{ neV} \)

Cell parameters:
• Loss per bounce 1e-4
• Non-specularity 100%
• \( V_f(\text{side}) = 91 \text{ neV (quartz)} \)
• \( V_f(\text{top\&bottom}) = 220 \text{ neV (DLC)} \)

Beam parameters:
• 10 uA average current
• 30 s beam gate spacing
• 2 s gate width (flapper open 2.25 s)
Comparison of nEDM Cell Loading

- Old source: approx. 100 UCN/cc/uC in the SD2.
- New source: MCNP prediction approx. 400 UCN/cc/uC in SD2.
- SD2 surface area $A_{\text{old}}/A_{\text{new}} = 1.9$

If we naively clamp an 8” SD2 volume onto a 6” flapper insert

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UCN Density in nEDM Cell

- Old Source
- New Source
- BigNew Source

Ratio of Old to New Source Cell Density

- $\rho(\text{New 6"})/\rho(\text{Old})$
- $\rho(\text{New 8"})/\rho(\text{Old})$
Cumulative Flux Across SD2 Surface (Flapper Open, UCNs produced at t=0)

New Source Geometry and Guides coupled to nEDM Cell

Old Source Geometry coupled to New Guides and nEDM Cell

Cumulative UCN Flux

- **SD2 Surface, Upward Transmission**
- **SD2 Surface, Downward Transmission**
## UCN density predicted by simulation

<table>
<thead>
<tr>
<th>Source</th>
<th>Location</th>
<th>Proton Current (μC)</th>
<th>Density (UCN/cc)</th>
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</thead>
<tbody>
<tr>
<td>Current</td>
<td>Source + Guide</td>
<td>5</td>
<td>52</td>
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<tr>
<td></td>
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<td></td>
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</tr>
<tr>
<td>New</td>
<td>Source + Guide</td>
<td>10</td>
<td>270 – 540</td>
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<tr>
<td>New</td>
<td>nEDM cell</td>
<td>10</td>
<td>150 – 300*</td>
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</table>

* Unpolarized density at T = 0
Engineering design of the new source
New source status

• “Flapper valve” assembly and SD2 volume fabricated

• Rest of the source is in the final engineering stage – awaiting input on how to cool the moderator volume
UCN transport system

- UCN guide baseline design (before the polarizing magnet):
  - Electropolished SS guides
  - Modified conflat joints (minimize gap)

- UCN guide status:
  - Guide components ordered, some of them delivered and vacuum tested
  - They will be tested in the current UCN beam time

- UCN spin polarizer
  - Superconducting magnet

- UCN spin polarizer status
  - Being set up to be tested
UCN guide preparation
SC magnet for UCN polarizer
nEDM cell prototype

- In order for the demonstration of stored UCNs to be meaningful, UCNs need to be stored in a realistic nEDM apparatus prototype that meets minimum requirements:
  - Electric field
  - UCN storage time
  - Compatibility with polarized 199Hg atoms
  - Cell valve
  - Cell switcher
  - Spin polarizer (SC magnet)
  - Spin analyzer
  - UCN detector
  - Magnetic field sufficiently uniform for Ramsey measurement
Our approach

• Small scale HV test apparatus
  - Study electrode material & shape (esp. at the cathode-insulator junction)
  - Study wall and wall coating materials

• 199Hg magnetometer test apparatus
  - Study wall coating material for spin relaxation and effect of HV reversal

• Cell valve, switcher, spin analyzer, UCN detector
  - Develop based on in-house capability
Small scale HV test apparatus

• Goal
  • Allow us to gain experience with HV in room temperature vacuum (as opposed to 0.4 K LHe)
  • Study the effect of various gases
  • Test various designs for electrode-insulator wall junction
  • Test various insulator wall and coating material

• Status
  • Vacuum chamber and stand delivered and assembled
  • 200 kV power supply ordered
  • 100 kV power supply also ordered and delivered (will be used for the commissioning of the apparatus)
  • Design of the initial electrodes in progress
HV Test Chamber
Hg Comagnetometer

- The basic system will be similar to the ILL experiment with a prepolarization volume and direct optical detection of the $^{199}$Hg precession in the UCN storage cell.
- An UV laser to access the 254 nm transition has been acquired and tested; over 40 mW available, need only 500 µW.

Hyperfine structure of natural Hg observed through laser light scattered by Hg contained in a cell.
Hg Comagnetometer

The optics, prepolarization, 254 nm detection, frequency determination are all well understood and fully developed technologies.

The only R&D issue is in regard to the UCN cell wall coating:

1. Must have high UCN potential, low UCN loss, low UCN polarization loss (lifetime in excess of 400 seconds)
2. Must have good Hg nuclear polarization storage properties (lifetime in excess of 200 seconds)
3. Properties must be stable under application of high voltage; previous work has shown instabilities

Work done in the early 1990’s showed that the instability was due to the generation of contaminants formed by microdischarges when high voltage is applied to the cell. These contaminants were identified and we are developing a technique to neutralize their deleterious effects.
LANSCE Run Schedule During Risk Mitigation Project

18-Jun-13

For Planning Purposes Only

Version 4.1

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<th>Feb</th>
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Approximate CY Operational Hours Available

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<td>2700</td>
<td>3300</td>
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<td>4000</td>
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Turn on
Outage
Outage w/ IPF production
Run Cycle
Warm Stand by

BGS 6/28/2013
Summary

- R&D toward a new nEDM experiment at LANL is under way.

- Simulation & design of the new source and guide system near completion, predicting a factor of ~5 increase in the stored UCN density.

- Installation of the new source and guide system scheduled for summer of 2015.

- R&D efforts on HV, 199Hg comagnetomter, magnetics, UCN detection and spin analysis are under way.