PFMO-Walls for UCN Storage

Ch. Duesing[1], S. Zimmermann[1], Y. Pokotilovski[2], P. Geltenbort[3], Ch. Plonka-Spehr[1]

(1) Department for Nuclear Chemistry, Johannes Gutenberg University of Mainz, Germany
(2) Joint Institute for Nuclear Research, Dubna, Russia (3) Institute Laue-Langevin, Grenoble, France

Abstract and Motivation

The free neutron lifetime is necessary for determining the fundamental coupling constants of weak interaction. Its precise value is also of importance for parameters of the $V-A$-Theory in combination with asymmetry data of neutron β-decay. Until 2010 its mean was calculated by the PDG from several experiments to $\tau_N = (885{,}7 \pm 0{,}8)\,\mathrm{s}$. Taking two new storage experiments into account in 2011 the value was lowered and the uncertainty scaled up by factor 2.7 to to $\tau_N = (881{,}5 \pm 1{,}5)\,\mathrm{s}$.

To support clearing this 'Puzzle of Neutron Lifetime' we are preparing an UCN-wall storage experiment with a novel wall coating. In storage experiments temperature depended, inelastic scattering is believed to be the most important of UCN losses upon wall collisions. Former, similar experiments could not be run at temperatures lower than $-160\,°\mathrm{C}$ limited by the physical properties of the polymer wall coating. Therefore the use of a novel perfluorinated polymer (PFMO), which consists only of carbon, oxygen and fluorine, with a lower pour point of $-159{,}3\,°\mathrm{C}$ was proposed. At temperatures around liquid nitrogen a loss probability of around 10^{-7} is expected.

This poster is about an UCN storage experiment to measure the characteristics and verify the suitability of PFMO coated walls. The complete experiment is planned to be run in late 2014, a pre setup had just been used at a beam time at ILL, Grenoble to test several components. One important part of the experiment is the coating, cooling and conditioning of the PFMO film. Big efforts have to be made to create a repeatable workflow, which leads to a complete wall cover of PFMO.
Medium-term an additional experiment based on this setup could be used to determine the free neutron lifetime.

Characteristics of PFMO

- **P**er**F**luorinated **M**ethyleneoxide **O**ligomers (**PFMO**):

  $C_4F_9(OCF_2)OC_4F_9$
- Synthesis by Perfluoration:

  $C_4H_9OCH_2OC_4H_9 + F_2/He \xrightarrow{NaF} C_4F_9(OCF_2)OC_4F_9$
- Impurity checked by NAA, ^1H-NMR, ^3C-NMR.
- Density: $1{,}73\,\frac{\mathrm{g}}{\mathrm{cm}}$
- Melting Point: $-159{,}3\,°\mathrm{C}$
- Boiling Point: $125\,°\mathrm{C}$
- Effective Wall Potential: $V_{calc} \approx 100\,\mathrm{neV}$

  Loss Coefficent: $\eta_{calc} = 3{,}8 \times 10^{-7}$

Experimental Process

1. **Evacuation** of the vacuum chamber with external heating, target pressure $p \geq 10^{-6}\,\mathrm{mbar}$.
2. **Cooling** of the copper storage bottle by pumping of lN_2 ($-196\,°\mathrm{C}$) through 16 concentrical pipes. Temperature adjustment by controlled lN_2 flow.
3. **Coating** of the inner walls of the storage bottle with PFMO with helium as a protection gas.
   - Liquid PFMO is vaporized and delivered into the storage bottle by a helium gas jet.
   - Coating nozzle at the end of a moveable tube to spray PFMO onto the cold surfaces where it freezes immediately.

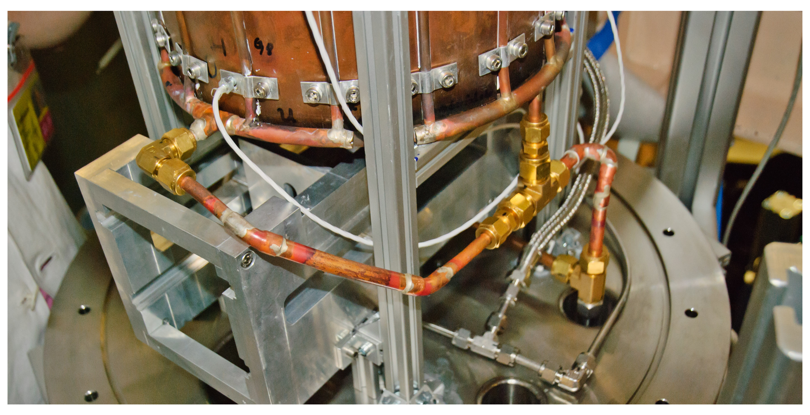
   

   - Repeated warming and cooling of the walls leads to a homogenous surface. Molten PFMO seals the slits between different components of the storage bottle.
   - Checking the coating with an USB camera.
4. **Re-evacuation** of the vacuum chamber.
5. UCN-**Storage Measurement** with varying 2 parameters:
   - Holding times from $2\,\mathrm{s}$ to $800\,\mathrm{s}$.
   - Varying the height of an absorber for different UCN spectra.

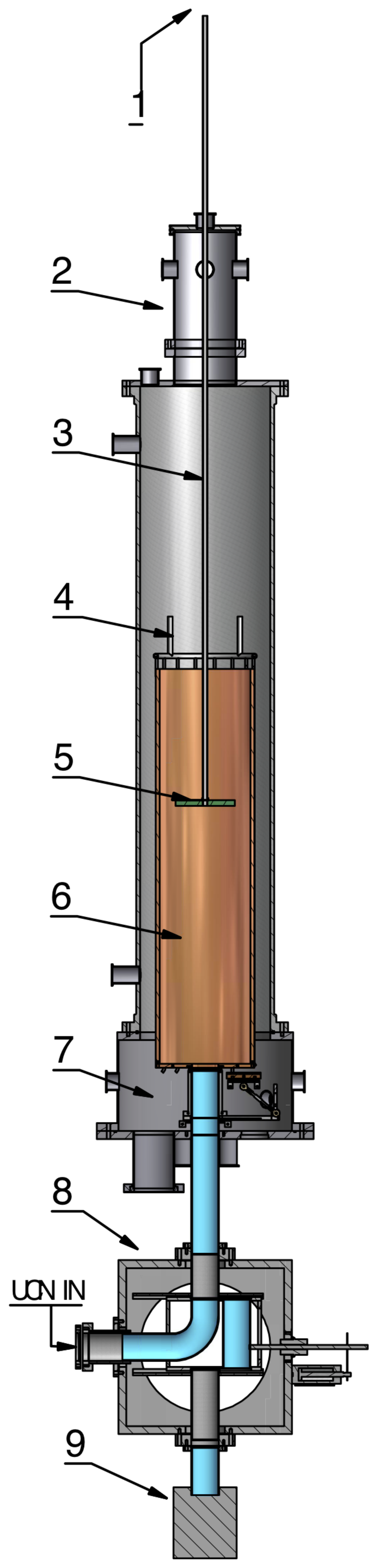
Experimental Setup

The experimental setup consists of

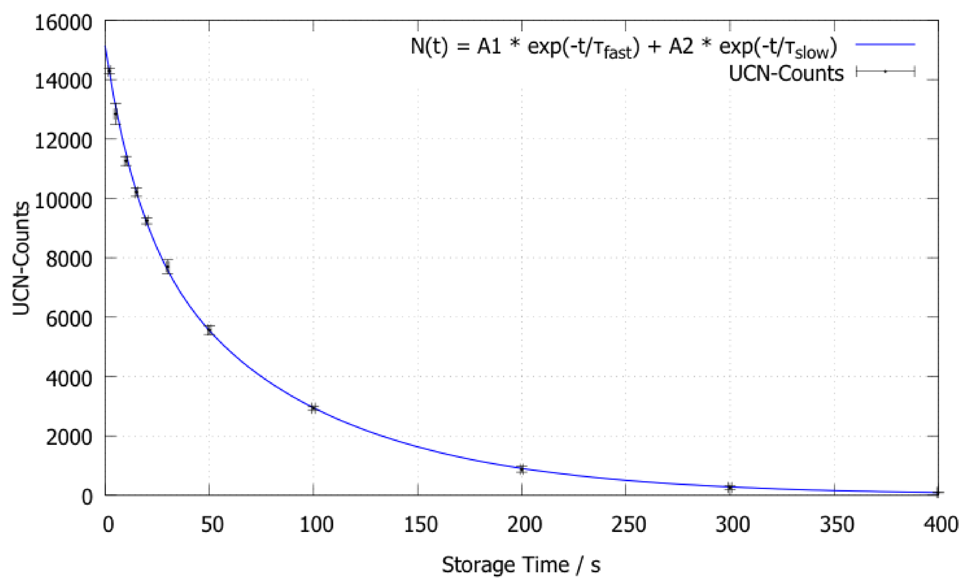
1. **Linear Actuator** (not displayed): Controlled motion of the PFMO-coating tube to achieve a homogenous coating and to set the absorber height.
2. **Gate Valve**: Allows the change between the coating nozzle with a camera and the absorber without breaking the vacuum inside of the chamber.
3. **PFMO-Coating Tube**: At the lower end of the tube the ^{10}B-absorber, the coating nozzle or an USB camera can be mounted.
4. **Cooling System**: 16 Concentrical copper pipes are fixed around the storage bottle for cooling by liquid and gaseous nitrogen. Cryogenic thermometers (PT 100) are mounted to monitor the temperature and check for gradients.

5. **Absorber / Coating Nozzle / USB Camera / Monitor Detector**: see 3.
6. **Storage Bottle**: Copper cylinder with volume: $44\,\mathrm{L}$, height: $1\,\mathrm{m}$ and diameter: $230\,\mathrm{mm}$. Reduced temperature gradients by inner heat flow. Inner surface coated with titanium to absorb high energetic UCN. Slits between bottom and cylinder respectively shutter plate are sealed by the PFMO coating.
7. **Shutter**: Copper plate with $\mathrm{lN_2}$-supply and temperature sensor. Driven by an pneumatic actuator, switching within $0{,}5\,\mathrm{s}$.
8. **UCN-Switch**: During the storage process the UCN pipes are changed from inlet to outlet.
9. **^{3}He-Detector**
10. **$\mathrm{lN_2}$-Dewar** (not displayed): Temperature control by a system of regulating valves for liquid and gasous nitrogen. Fine tuning of the N_2-flow leads to a constant temperature of the storage bottle for hours.
11. **He-PFMO-Gas-Jet** (not displayed)



First Results



- The exponential decay of the storage curve consists of a fast and a slow UCN component:

$$N(t) = A_1 \cdot \exp\left(-\frac{t}{\tau_{\text{fast}}}\right) + A_2 \cdot \exp\left(-\frac{t}{\tau_{\text{slow}}}\right)$$

- As expected the PFMO coating reduces UCN losses as shown by the first measurements at the ILL:

$$\tau_{\text{slow, titanium}} = (3{,}98 \pm 0{,}13)\,\mathrm{s} \quad \chi^2_{red} = 0.36$$

$$\tau_{\text{slow, PFMO}} = (84{,}91 \pm 2{,}12)\,\mathrm{s} \quad \chi^2_{red} = 1.27$$

- Performing several measurements at a constant temperature of the storage chamber and thus of PFMO
  → Successful and repeatable cooling with lN_2.
- USB Camera failure:
  → No information about the quality of the coating.
- Temperature Monitoring:
  → Partial failure of sensors due to poorly heat transfer.
- All actuators have to be tested several 1000 times to prove reliability.

Outlook

Features of the intended experiment are:

- Long term operation of all drives: Several 100 measurements are necassary.
- Improved observation methods: Estimation of the conditions of PFMO and the sealing of slits.
  - Vacuum and low temperature suitable USB camera.
  - Test of different methods as in situ reflectometry or transmisson spectroscopy.
- Using a monitor detector:
  - Measuring at different heights provides UCN spectrum.
  - Monitoring to respect UCN flow fluctuations.
- Selection of a small range of the UCN energy spectrum:
  - Absorber (^{10}B / lithium stearat) for high energy cut-offs.
  - Thin foils in the feeding guide for low energy cut-offs.
- Optimizing the recovery of the preicous PFMO.

- Measuring of the effective wall potential of PFMO with a separate experiment.
- MC-Simulations for comparison with experimental data.