UCN source at PULSTAR reactor

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Outlines

1. Source design overview
2. Source cryostat design
3. Cryotest set-up overview
4. First Results of SD2 growing and manipulations
Properties
- Heavy loading of U-235 -- 12.5 kg
- Low ratio of H to U-235 atoms
- High ratio of fast to thermal flux in the core

Benefits
- Long core lifetime
- High sensitivity to reflector material
- High fast-flux leakage
PULSTAR 1 MW reactor at NCSU campus

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Conceptual design

LANL pulsed prototype source:
• proton+tungsten as a neutron source
• Be reflector
• 5K & 77K Poly as pre-moderators
• D2 crystal grown from vapor
• 120 UCN/cc in horizontal guide measured
• LHe dewar
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PULSTAR conceptual design (2005)
• reactor as a neutron source
• Graphite reflector
• D2O (300K) and solid methane (~40K) as pre-moderators
• D2 crystal can be grown from vapor
• ~ 30 UCN/cc at the exit port predicted
• flow of LHe
Engineering design

- Nose post/shielding box with He gas handling system
- Heavy water tanks and circulation system
- Methane gas handling system
- Deuterium gas handling system
- LHe plant and cooling loops
- UCN source cryostat and UCN guides
Test assembly on the Bioshield Door
UCN source cryostat design

- All materials has to be neutron friendly
  - Low capture cross section
  - Negligible long life time activation
  - Radiation resistant – no plastics, no elastomer seals
- We need cryogenic materials with good and very poor thermal conductivity
- Choice of materials:
  - Aluminium – Al6061 as structural and 1100 as a good conductor
  - Titanium – Ti6Al4V as thermal isolator
  - Zirconium – Zircaloy
Cryogenic cooling loops design
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use of intermediate 500l LHe Dewar allow us to control He supply temperature by using different height of the withdrawal tube.
Engineering challenges: Cryostat design
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CFD simulation: final design of cooling channels

200g of SD2; 1.35kg of Al, total nuclear heat 1+2.5 W, this run has additional 2 W from walls and 2 watts of black body radiation
Methane container design

- Methane volume 1.4 liters
- Mass 680 g
- Container mass 2.35 kg of AL
- Total nuclear heat 4.3 + 2.8 = 8.1 W
Para-to-Ortho converter & Raman spectroscopy

- Equilibrium deuterium in 2-to-1 ratio of ortho- to para- spin states, coupled to even and odd rotational angular momentum
- Converter prepares few percent ortho- state utilizing Chromium(II) Oxide (Oxysorb) or Iron(III) Hydroxide at triple point
- We have developed a procedure to make crystal Iron(III) Hydroxide
- The converter was tested with both materials

Raman Spectroscopy
- Spectrometer precisely determines para- to ortho- ratio of sample
- Allows for strict limits on the hydrogen, HD contamination, a source of up-scattering
- Pictured are Stokes lines of deuterium
CRyogenic testing overview

- All tests are done outside biological shield.
- Up to now we have completed the following tests:
  - Methane condensation to test instrumentation and LHe system operation.
  - N-deuterium condensation through liquid phase to test instrumentation and LHe system operation.
- At present, we are in the middle of ortho-SD2 sublimation study.
Cryogenic testing of methane container

**Figure 1:** Pressure and temperature of the deuterium cryocontainer over time as it was allowed to cool and warm.

<table>
<thead>
<tr>
<th>Flow (LPM)</th>
<th>Heater (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>15  40  80</td>
</tr>
<tr>
<td>15</td>
<td>10  30  60</td>
</tr>
<tr>
<td>27</td>
<td>10  30  40</td>
</tr>
<tr>
<td>34</td>
<td>10  25  35</td>
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*1: Equilibrium temperature (K) of methane cryocontainer.*

**Figure 2:** Pressure and temperature of the deuterium cryocontainer followed the neon saturation curve while cooling, although the measured temperature was higher during warming.
SD2 monitoring system for visual control

- Idea of the test came from Albert Young and was implemented by Graham Medlin
- A monitoring system which allows to observe D2-container by using camera outside cryostat
Future cryogenic test plans

- Installation of the monitoring system
Sensors to monitor SD2 temperature

- 4 calibrated diode have been mounted on plastic holder 1 cm apart
- The holder has a disk to pull it down by gravity, the diameter of the disk is 1 cm
- The holder with sensors was placed at the bottom of the cryostat right below the mirror
SD2 growing tests: instrumentation details

- D-container bottom flat area is 5 cm diameter
- D-container He inlet Cernox TSD.1a
- D-Container He return diod
- D-Container He inlet Cernox
- GR Cernox
- GR heater, 20W
- D heater, 20W
- D-container Cernox TSD.1b

16 cm
SD2 growing test 1

• We started from Mainz TRIGA recipe:
• cold bottom, slow D2 flow about 0.4 l/m;
• then anneal at 14K - we did at 12.5K
• in addition, we did melting and re-freezing of SD2 crystal

“How to prepare a good SD2 crystal?”

Freezing the UCN converter from gas phase

- Procedure is important for quality
- Keep the converter temperature constant at 6K (+/- 0.1K)
- Growing speed < 4mm/h
SD2 growing test 1, no heaters, D-inlet 5.4K
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SD2 growing, no heaters, D-inlet 5.4K, flow up
SD2 growing, no heaters, D-inlet 5.4K, flow up

Large flow, 1-2 l/m
1-3 cm are embedded
4 cm is just above surface
SD2 growing, GR heaters on, D-inlet 5.4K

Gradient ring heater on

Temperature (K)

Time Feb. 24\textsuperscript{th}-Feb. 25\textsuperscript{th}

- D\textsubscript{2} container
- 4 cm
- 3 cm
- 2 cm
- 1 cm
- D\textsubscript{2} inlet
SD2 growing, GR heaters on, D-inlet 5.4K
SD2 growing, GR heaters on, D-inlet 5.4K
SD2 growing test 1: end of annealing at 12.5K

Figure 8: Pressures and temperatures while annealing.
SD2 growing test 1: melting, liquid D2

D2 pressure 435

2016:03:01 16:43:49
SD2 growing test 1: melting, liquid D2

D2 pressure 435

2016:03:01 16:43:49
SD2 growing test 1: start of re-freezing
SD2 growing test 1: end of re-freezing overnight

D-inlet = 6.07K; TSD.
1a = 16.3K,
1b = 16.7K;
4cm = 14.5K;
3cm = 12.347.
2cm = 12.184,
1cm = 12.139K;
SD2 growing test 1: cooling down to 5K

13:38 noticed that 3cm=5.09K is cooler than 2cm=5.18K, 1cm=5.13; TSD.1a=8.67K; 1b=8.72K;
SD2 growing test: complete cool down

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SD2 growing test 1, conclusions

- with cold bottom around 6K and flow of 0.4 l/m, a dense and milky multi crystal is growing
- under the same conditions, except the flow was increased to 1-2 l/m, D2 sublimates as fluffy snowflakes
- melting and re-freezing results in visually quite good crystal
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we need warmer container to grow transparent crystal from gas phase - start using heaters!
SD2 growing test 2, inlet at 8K, top at 18K
SD2 growing test 2, inlet at 8K, top at 18K
SD2 growing test 2, inlet at 8K, top at 18K

Totally Transparent SD2 crystal
SD2 growing test 2, accidental melting & re-freezing, Mar 15
SD2 growing test 2, accidental melting & re-freezing, Mar 15
SD2 pressure was changing from 0.3 (11K) to 1.4 (12.2K) mbar

D-return (He gas downstream of cryostat) was changing from 12.5 to 15.8 over period of 20 min;
After one night in cryostat at T=12K
SD2 growing test 2, overnight dwelling Mar 16

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After one night in cryostat at T=12K.
SD2 growing test 2, inlet at 8K

• More D2 was added next day

D2 flow=0.75 l/m; D2 HP=15.5mbar stable; D-inlet=8.3K; 1cm=16.9K; 4cm=24.3K;
SD2 growing test 2, inlet at 8K

- Overnight D-container was at the similar but stable temperatures
SD2 growing test 2, inlet at 8K

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D-inlet=7.2K; D2 LP=2.33K (12.7K); 1-2 cm= 12.81K, 13.325 K  2cm still cooling toward 1 cm;
3-4 cm=17.7, 21.10K; TSD.1a,b were warming overnight with D-inlet (effect of small leak in TT1)

1 and 2 cm sensors are embedded in SD2
SD2 growing test 2, conclusions

• We succeeded to grow transparent crystal

• For clear crystal growing
  • the CONTAINER bottom needs to be pre-heated to about 12K
  • the temperature of the GROWING layer should be in the range of 12K-14K
• The next idea was to try simulate SD2 conditioning by pulsed heat

• We can not follow the same pattern as PSI or LANL beam, so the duration of the heat plus was chosen such way as to allow walls heats up to 14.5K, while SD2 was heated only from 8K to 9.5K and the interval between pulses was sufficient to cool everything down to the same condition:

• pulse 3 min, total cycle about 30 min
SD2 growing test 3, inlet at 8K, heat pulsing

Before heat pulsing
SD2 growing test 3, inlet at 8K, heat pulsing
SD2 growing test 3, inlet at 8K, heat pulsing
SD2 growing test 3, inlet at 8K, heat pulsing
More D2 was added next day

SD2 growing test 3, inlet at 8K, heat pulsing

after 54 cycles
SD2 growing test 3, decoupling from walls

During heat shooting

During annealing and warming
Conclusions from SD2 manipulations

- For transparent crystal, the initial temperature of the container must be at least 8K and D2 flow 0.8 l/m to keep surface at minimum 12K, D2 pressure about 20 mbar.

- Solid deuterium has very high mobility. During annealing in presence of wall gradient SD2 very fast re-shape itself (re-condensing) to the most cold spot, following constant T surfaces.

- Simulations of fast wall warming while SD2 stays cold (54 cycles) leads to surface degradation and results in Moon-like eroded surface.

- Leaving Moon-like crystal in the cryostat for another couple of days resulted in SD2 almost completely thermal decoupled from container walls.

- We are planning to study more of Long Time behavior of SD2.
Our team

A. Young, P. Huffman, R. Golub, A. Hawari

Graham Medlin

Grant Palmquist

Also thanks for help to our new members: Kent Leung and Christian White