Neutronics for new UCN source

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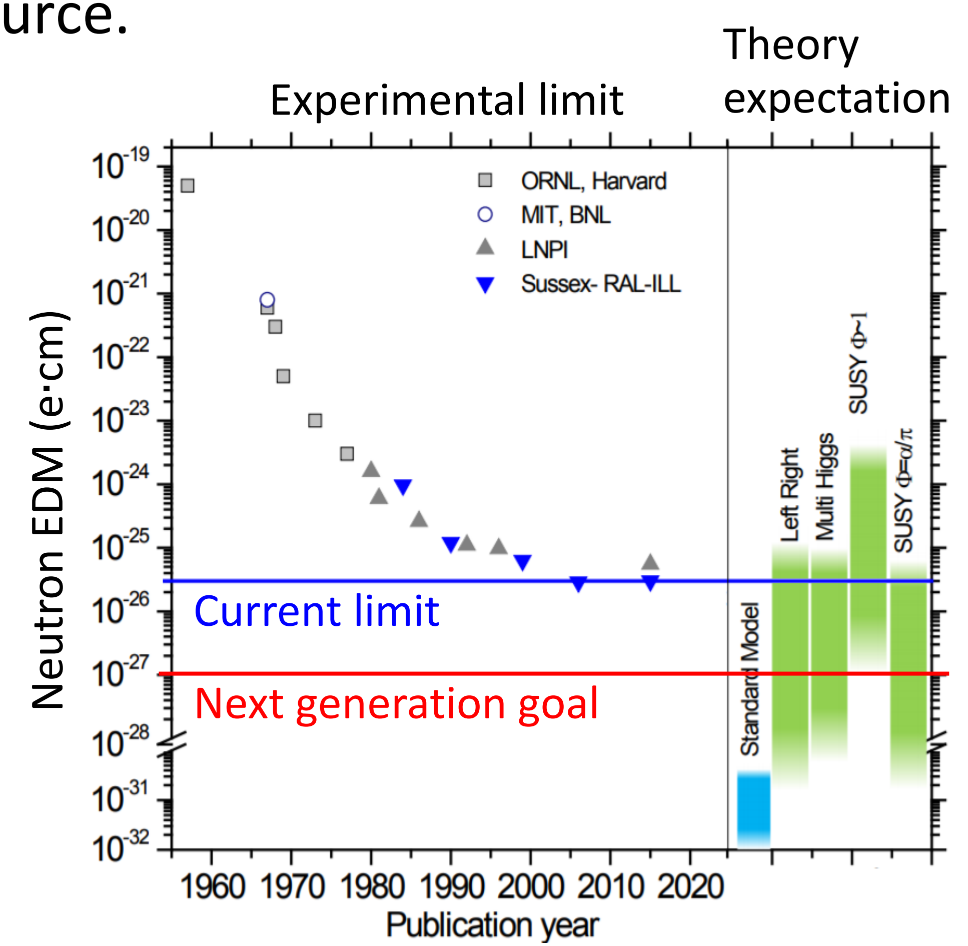
for the TUCAN collaboration

KEK-TRIUMF symposium

December 14, 2017

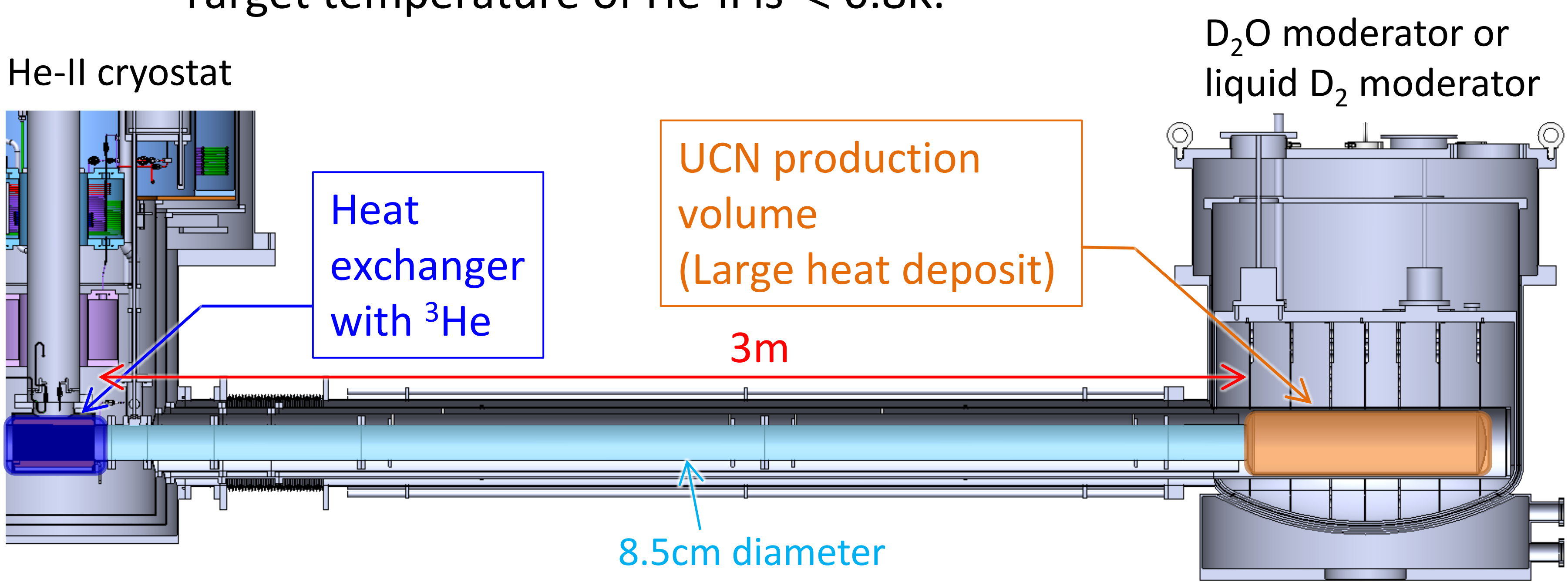
New UCN source

- Goal of next generation neutron EDM search: 10^{-27}e·cm
- Statistical error is dominant in the recent neutron EDM search.
- Upgrade of the UCN source is essential.
- Requirements to new UCN source.
  - High UCN production rate ($>2.3\times10^{7}$ UCN/sec.).
  - High UCN transportation rate ($>$4%).
  - Low heat deposit in He-II ($<$5W).
  - Low activation of UCN source.
  - High heat transfer in He-II.
    → Reported by Okamura-san.



Original plan of new UCN source

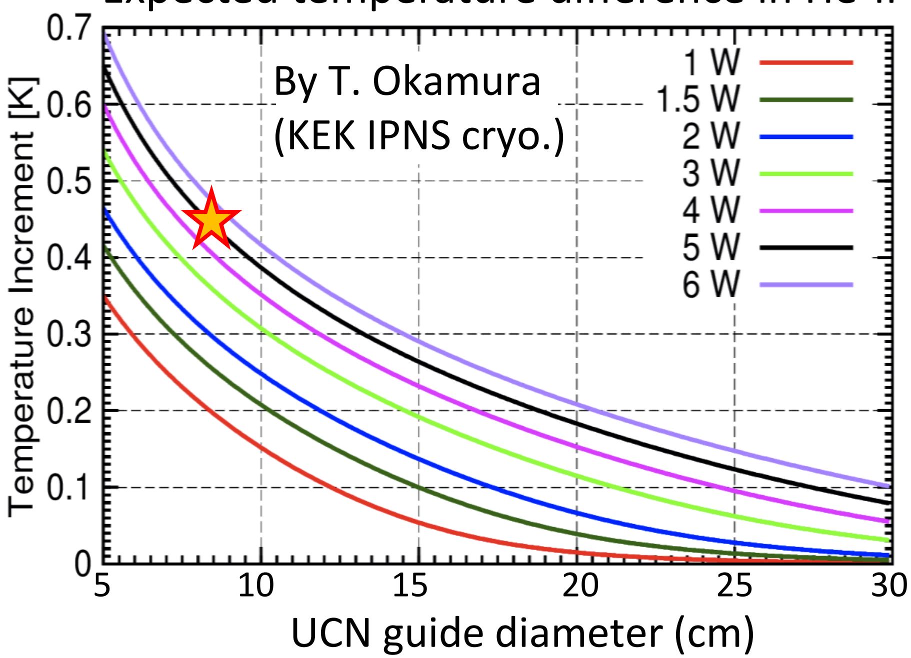
- He-II must be kept cold to suppress UCN upscattering.
- Cooling power of current cryostat is not enough for 20kW beam.
- Original plan of new UCN source.
  - Heat exchanger with ^{3}He is 3m distant from UCN production volume.
  - He-II is confined by aluminum foil.
  - UCN storage volume is filled with He-II.
  - Target temperature of He-II is < 0.8K.



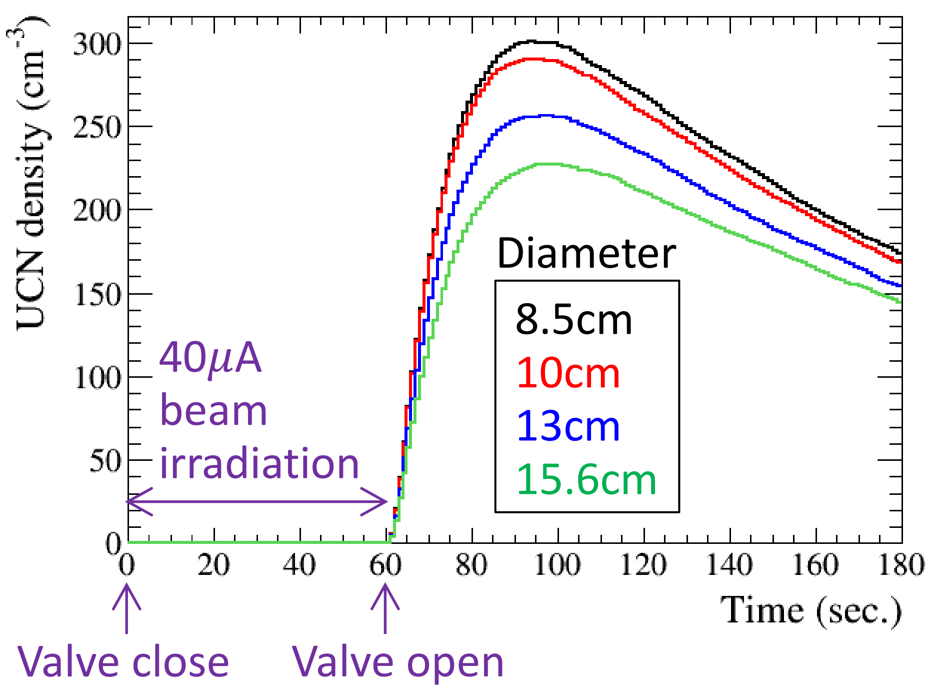
Heat transfer issue

- Heat transfer of original design was found to be not enough.
- It can be improved by enlarging UCN guide diameter.
- But large-diameter UCN guide decreases UCN density.

Expected temperature difference in He-II



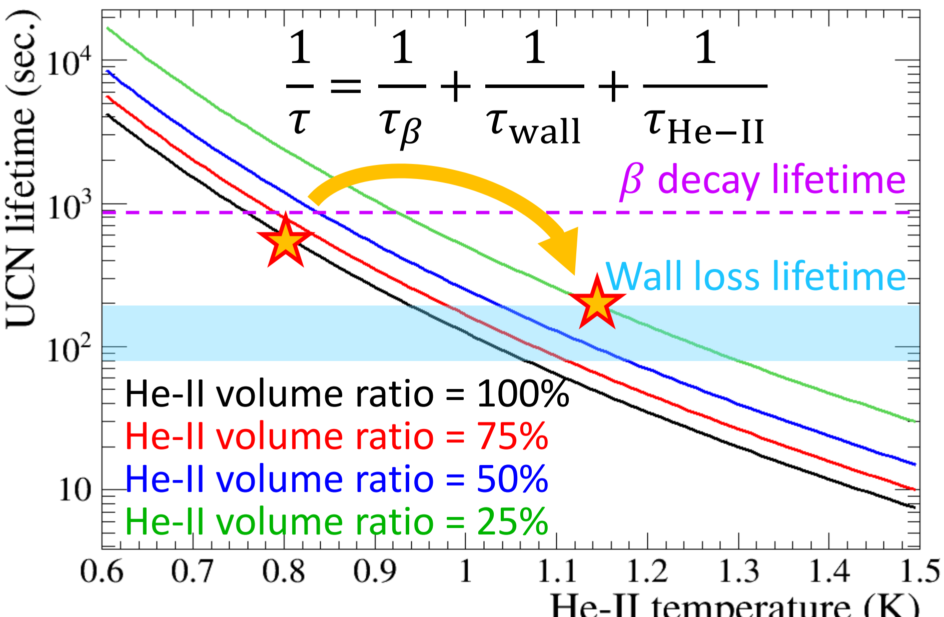
Expected UCN density in EDM cell



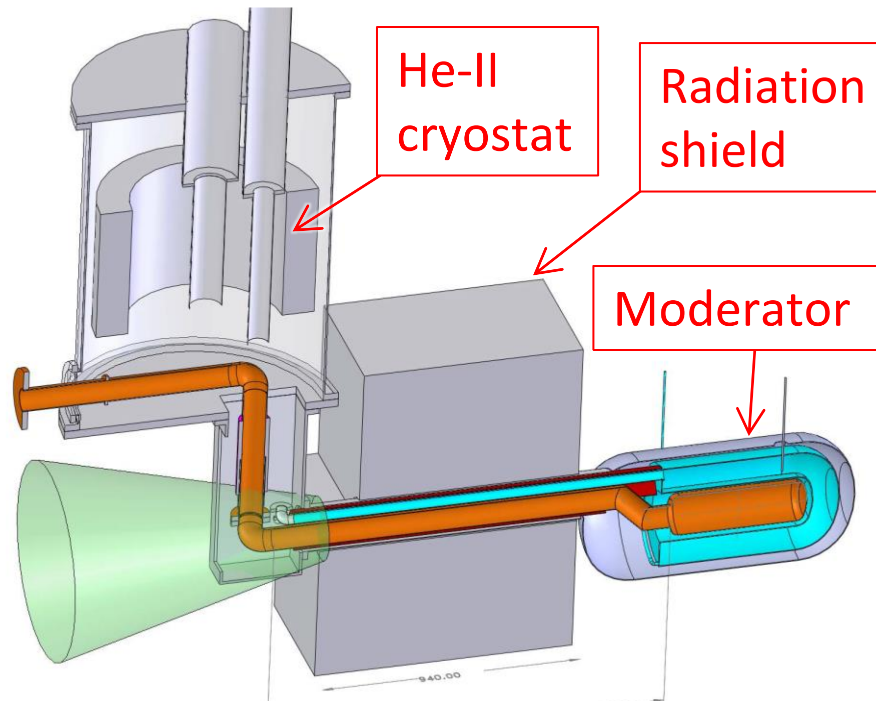
Updated plan of new UCN source

- Moderated the target temperature of He-II to 1.0-1.2K.
  - Confine He-II by gravity.
  - Reduce He-II volume ratio to 25% level.
- Cooling method options.
  - Heat exchange with ^{3}He (primary).
  - Direct pumping of He-II (alternative).

UCN lifetime due to upscattering in He-II

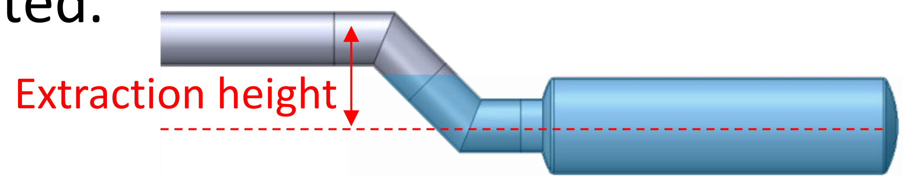


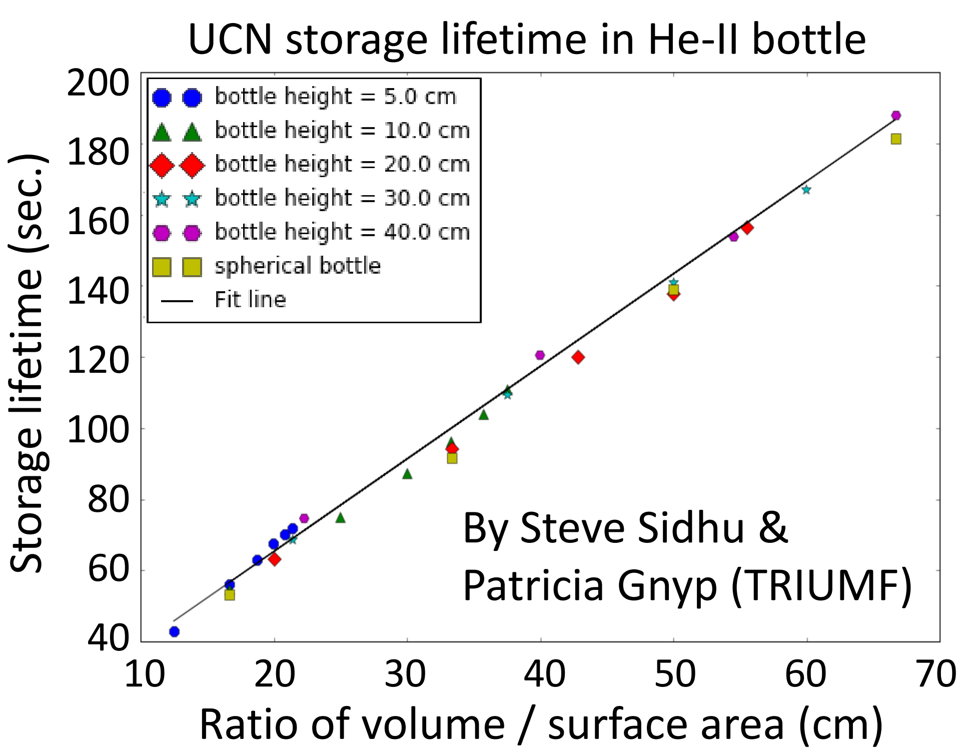
Conceptual design of new UCN source

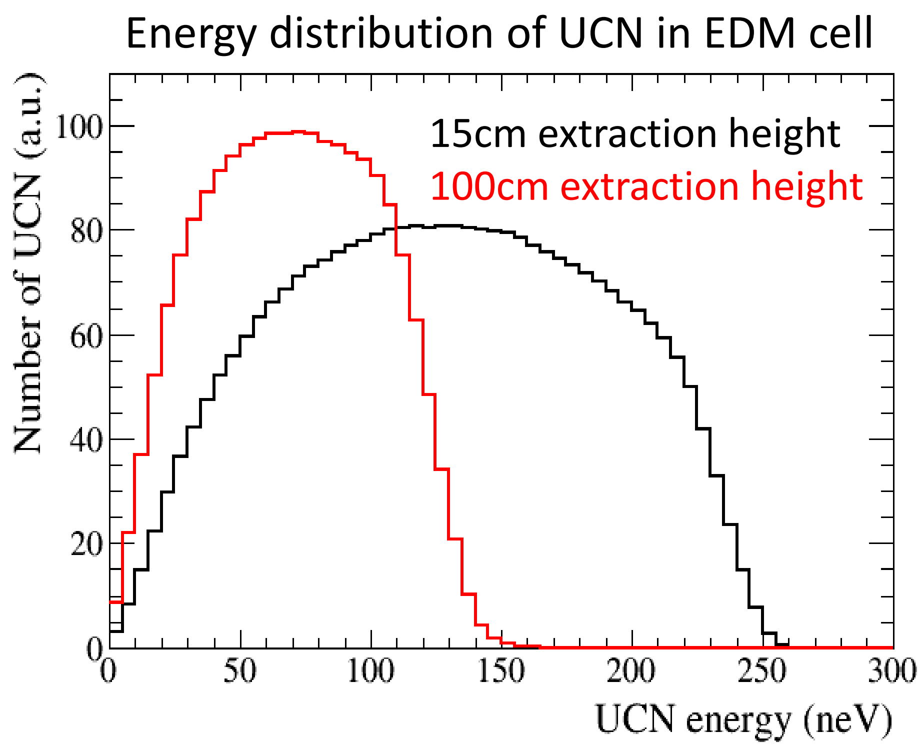


He-II bottle and UCN extraction

- UCN storage lifetime in He-II bottle is proportional to ratio of volume / surface area. (Bottle shape does not matter.)
- If extraction height is large, only low energy UCN are extracted. (Low energy UCN are more useful for EDM measurement.)

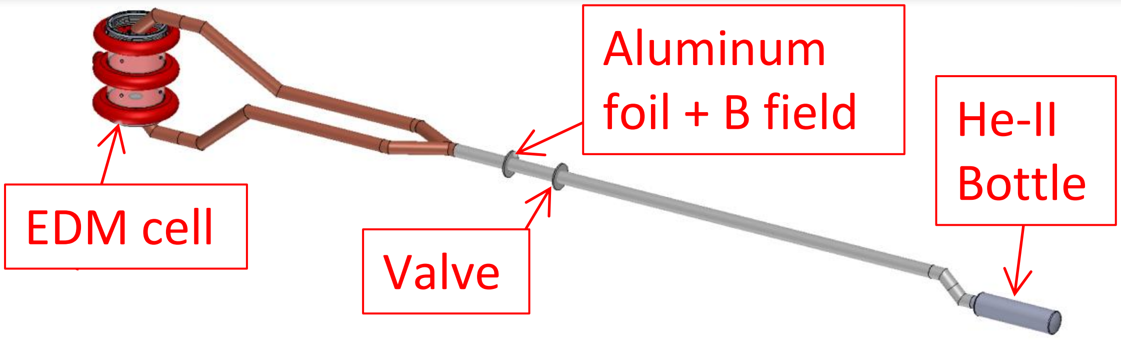






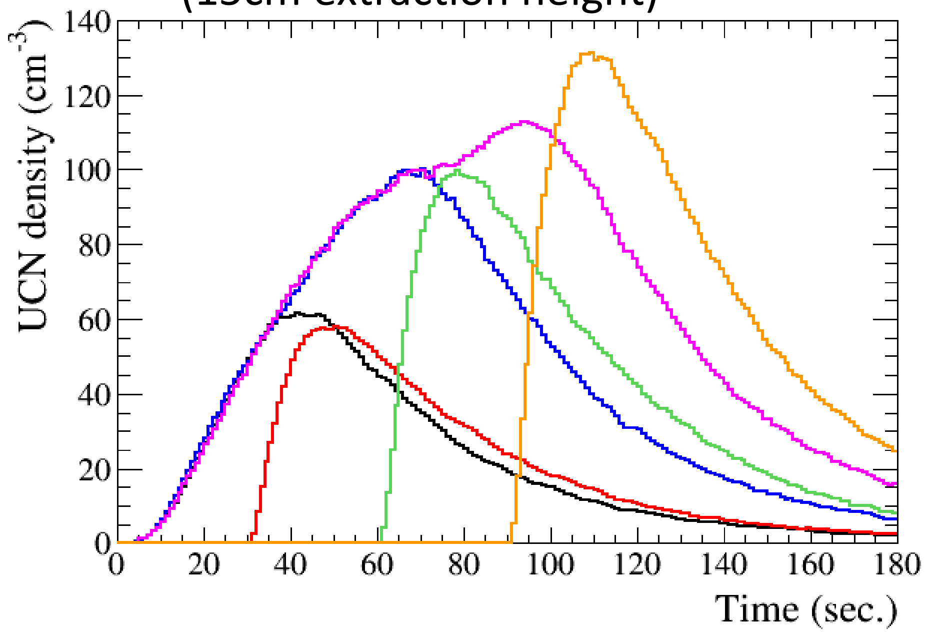
Beam irradiation time and valve operation

- Beam irradiation time and valve operation is being optimized.
  - Steady mode:
    Valve is always open.
  - Batch mode:
    Valve opens after beam.

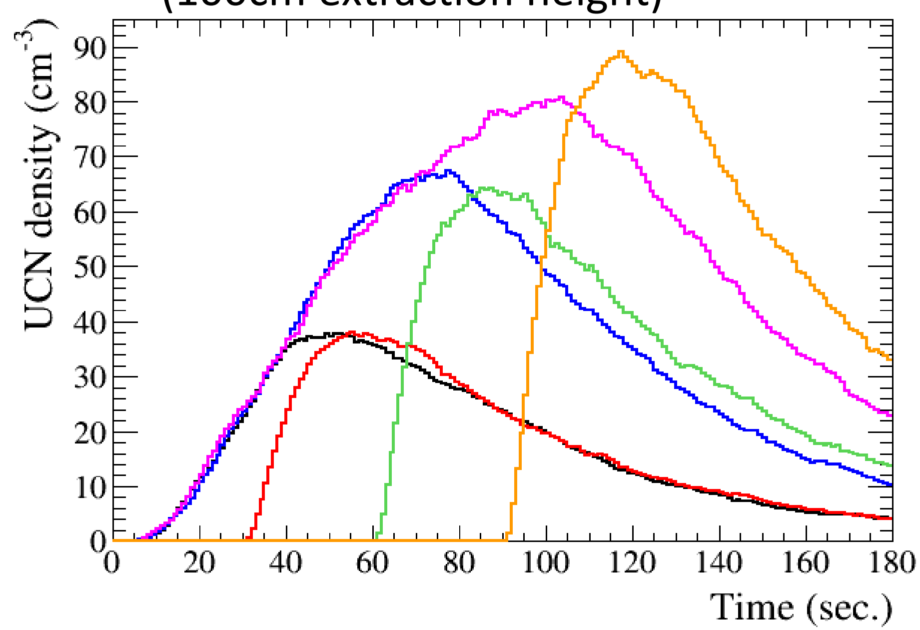


Steady mode (30 sec. beam)
Steady mode (60 sec. beam)
Steady mode (90 sec. beam)
Batch mode (30 sec. beam)
Batch mode (60 sec. beam)
Batch mode (90 sec. beam)

Expected UCN density in EDM cell (15cm extraction height)



Expected UCN density in EDM cell (100cm extraction height)

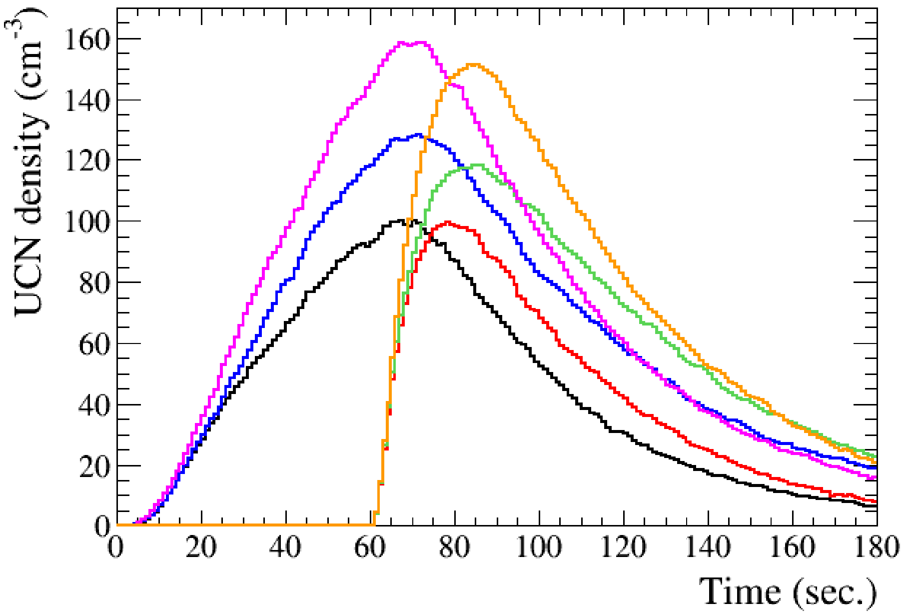


Spin flip effect

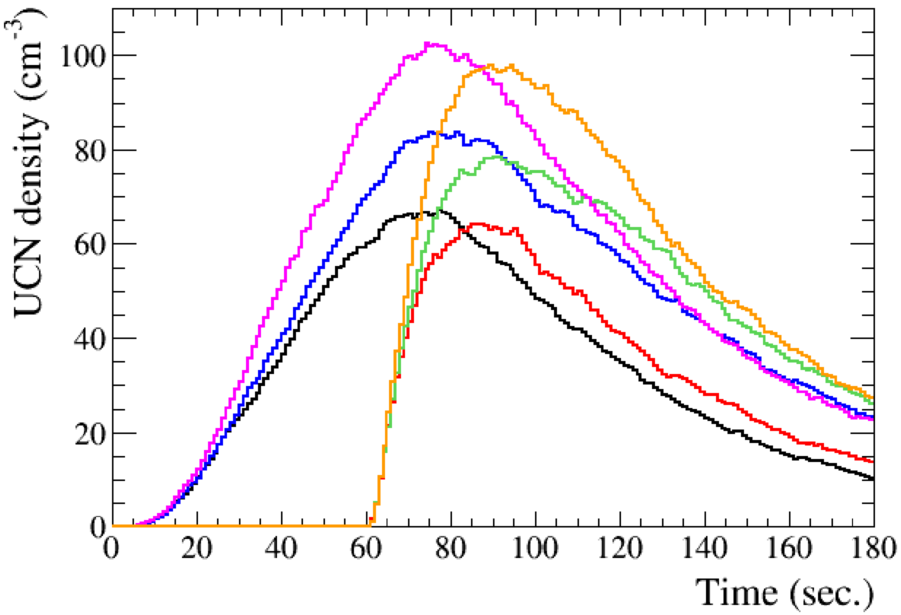
- Spin flip before valve will increase UCN density in EDM cell. (Spin flip after valve was assumed to be 0.)

Steady mode (spin flip prob. = 0)
Steady mode (spin flip prob. = 0.001)
Steady mode (spin flip prob. = 0.1)
Batch mode (spin flip prob. = 0)
Batch mode (spin flip prob. = 0.001)
Batch mode (spin flip prob. = 0.1)

Expected UCN density in EDM cell (15cm extraction height)



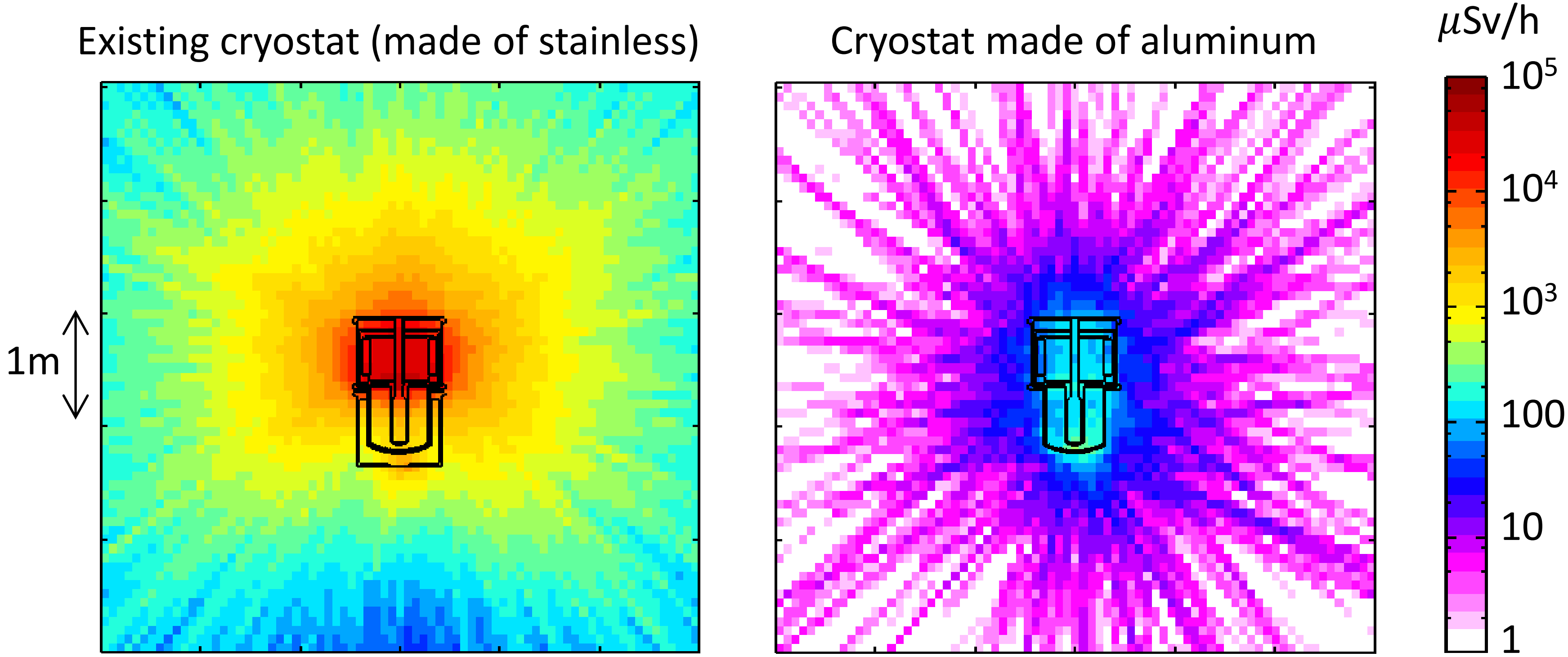
Expected UCN density in EDM cell (100cm extraction height)



Activation of cryostat

- He-II cryostat must be placed near the UCN production volume to reduce the He-II volume ratio.
- Activation of cryostat is a large concern.
- It can be reduced by making the cryostat with aluminum and placing lead + B_4C shield around the cryostat.

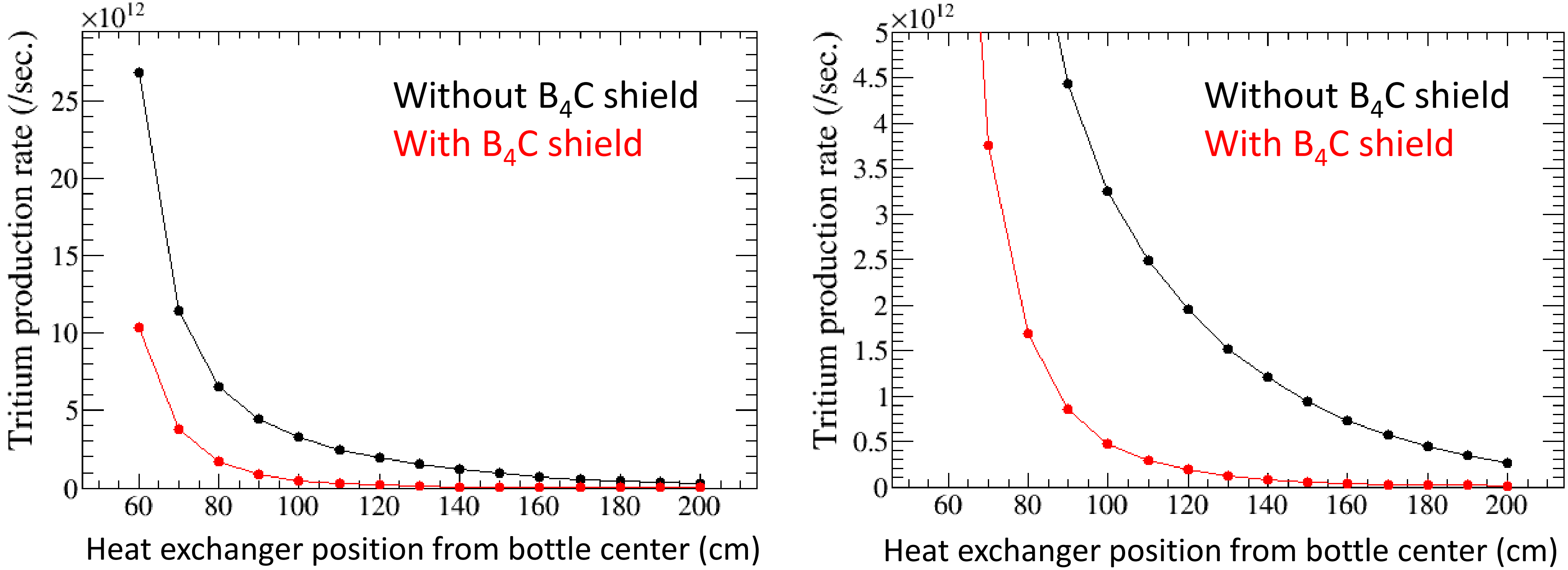
Residual dose rate after 8 months of beam (20kW×25% duty cycle) and 1 month of cooling.



Tritium production in ^{3}He

- Tritium is produced in ^{3}He.
  $^3\mathrm{He} + n \rightarrow {}^3\mathrm{H} + p$
- It can be reduced by placing B_4C shield around heat exchanger.

Tritium production rate in ^{3}He around heat exchanger at 20kW beam

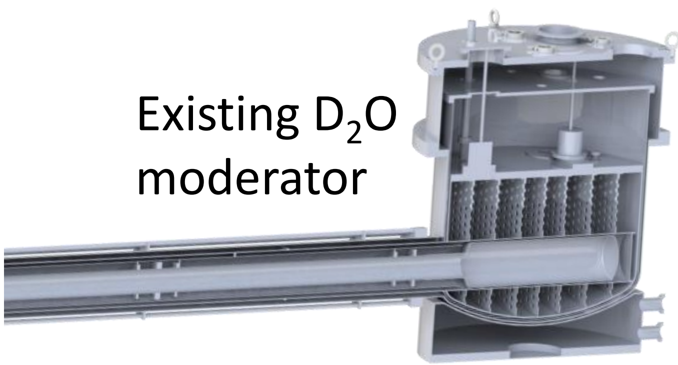


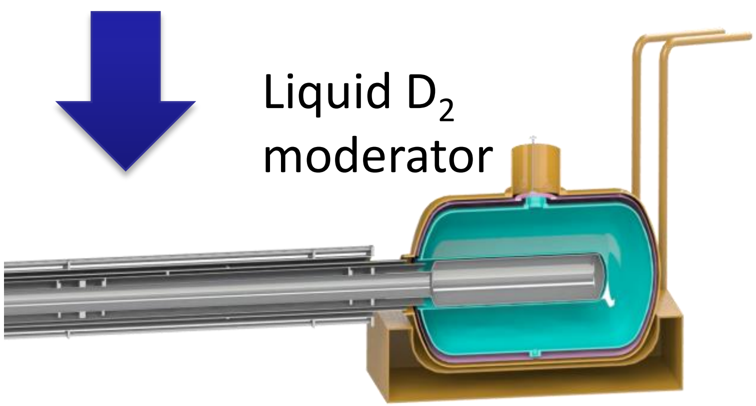
Zoom

Upgrade of neutron moderator

- We are currently using D_2O moderator.
- Liquid D_2 moderator will increase the cold neutron flux to superfluid helium (*i.e.* UCN production rate).
- Safety issue: liquid D_2 is explosive.
- Optimizing the geometry by MC simulation.

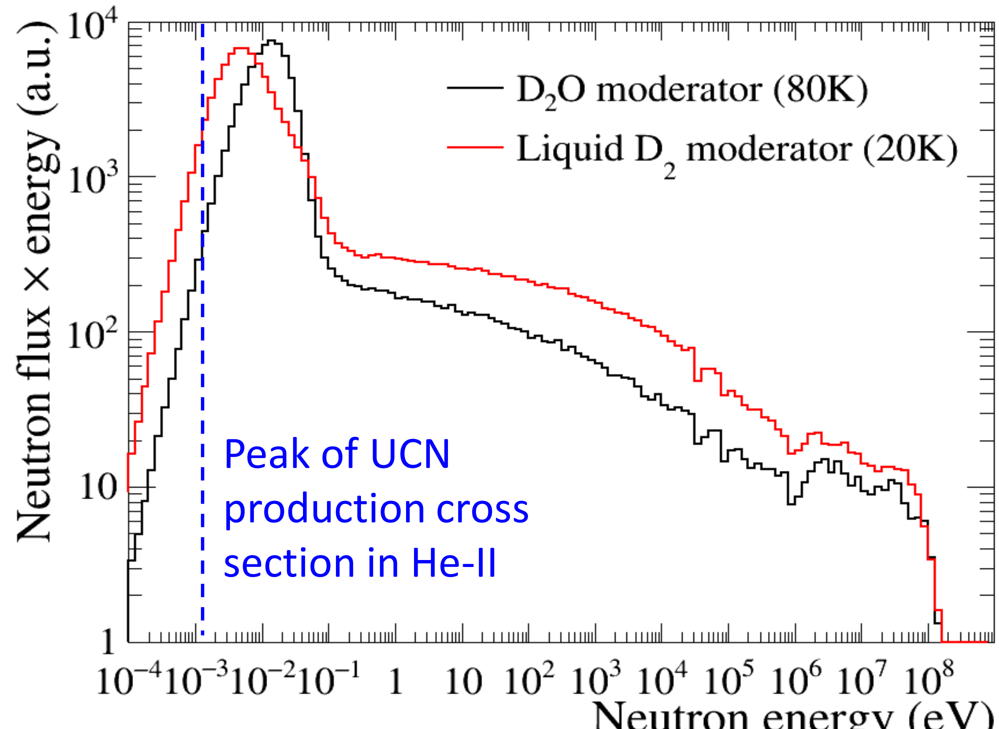
Existing D_2O moderator





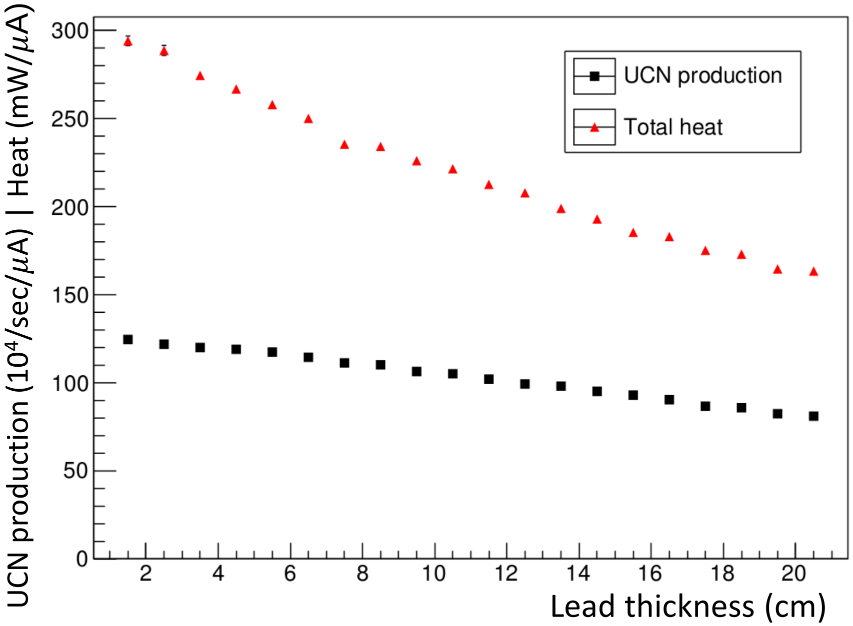
Liquid D_2 moderator

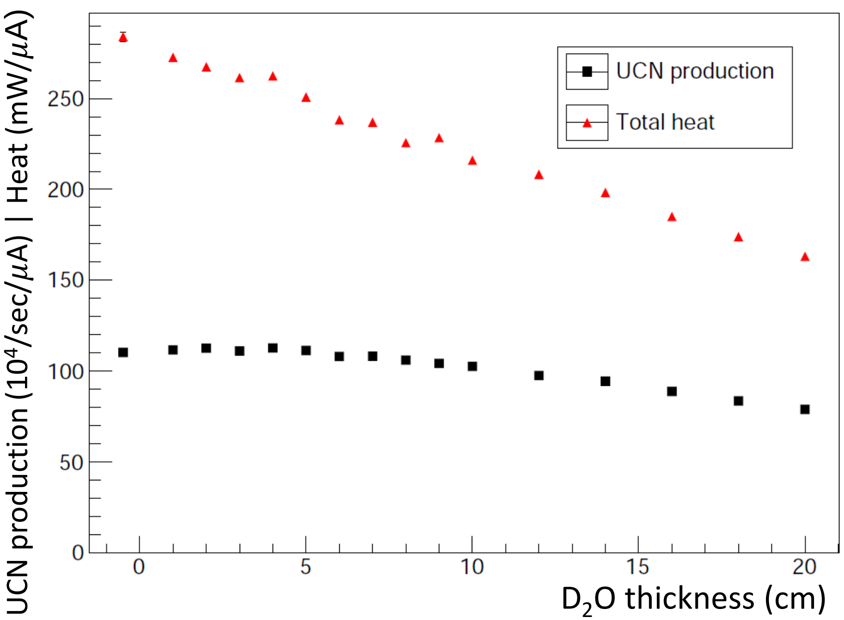
Neutron spectrum to superfluid helium (MCNP)

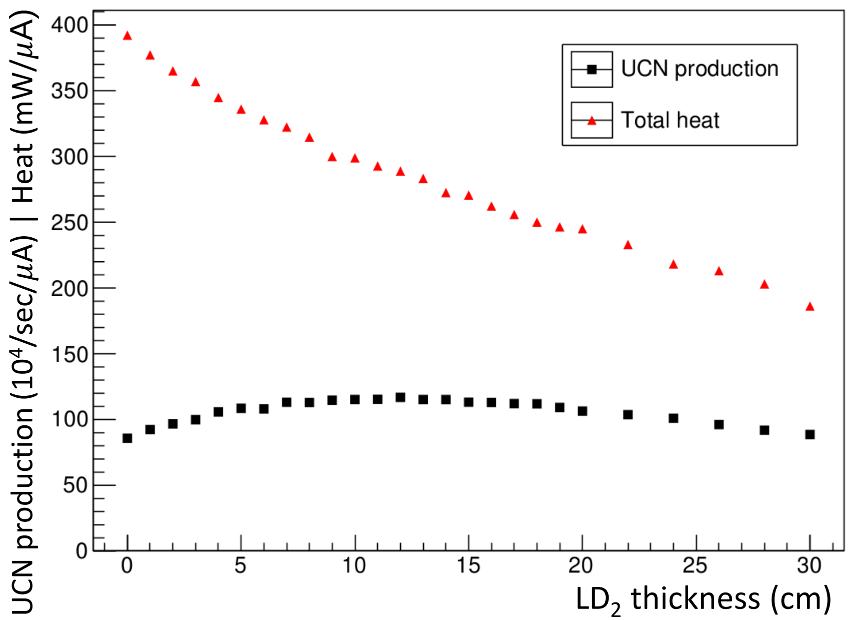


Optimization of neutron moderator

- Geometry of the neutron moderator is being optimized by MC simulation in terms of UCN production rate and heat deposit. (W. Schreyer)
- Discussing safety issue with TRIUMF safety group.



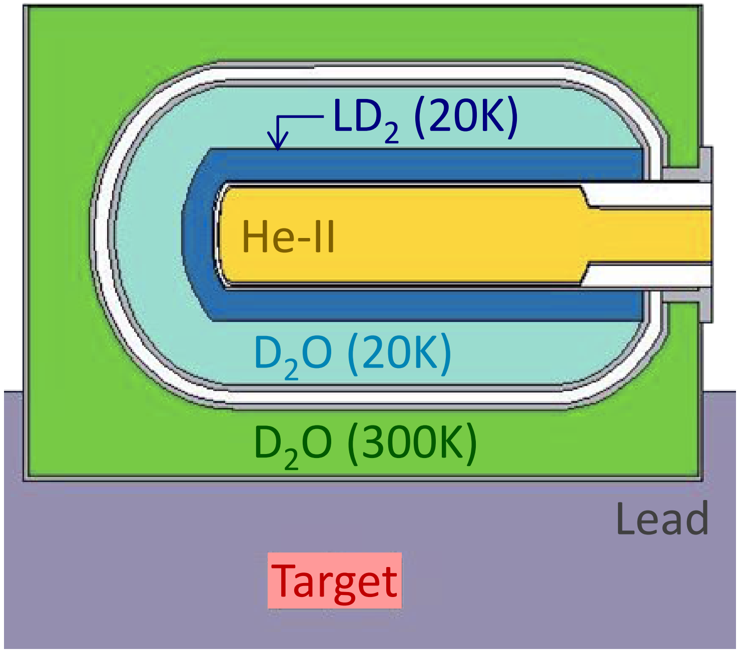




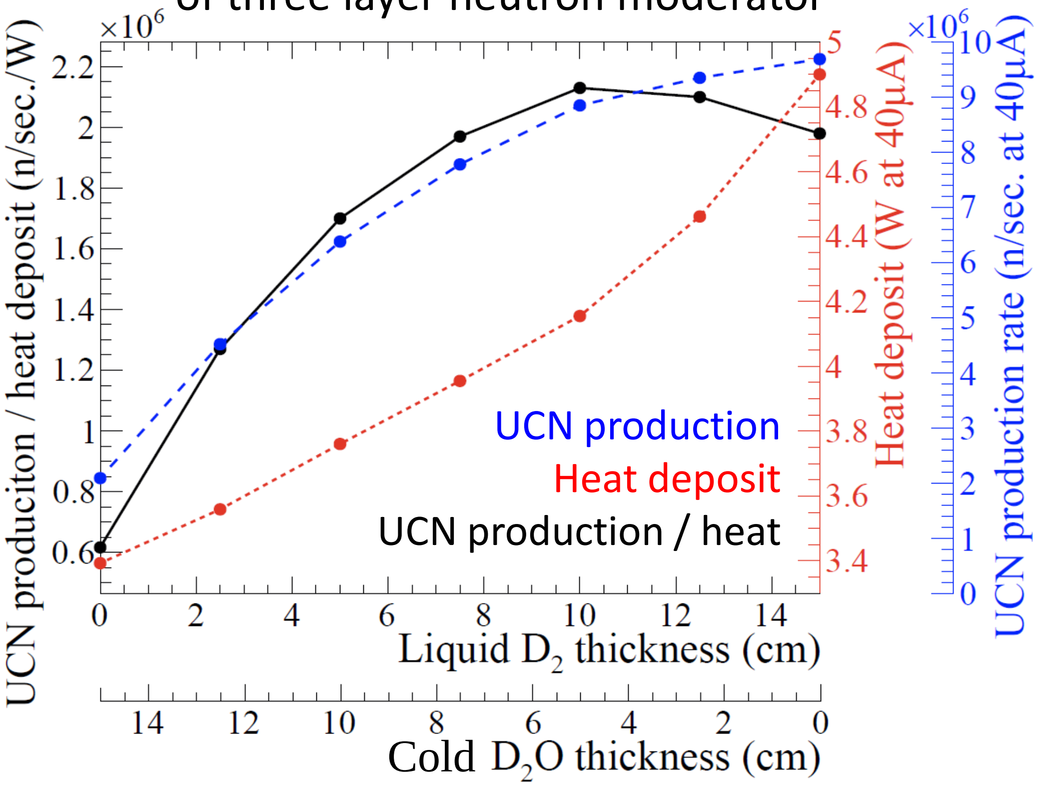
Three layer neutron moderator

- Liquid D_2 volume should be small for safety.
- It can be reduced without losing UCN production rate by adopting the three layer structure of warm and cold D_2O and liquid D_2.

Three layer neutron moderator



UCN production and heat deposit of three layer neutron moderator



Summary

- Upgrade of UCN source in the TUCAN experiment is essential for the world most precise measurement of neutron EDM.
- Basic conceptual design of the new UCN source was substantially modified.
- Optimization by Monte Carlo simulation is ongoing.
- Aiming to determine final design in 2018, start fabrication in 2019 and start operation in 2021.