TDR Assumptions for Pulsed Neutron Source

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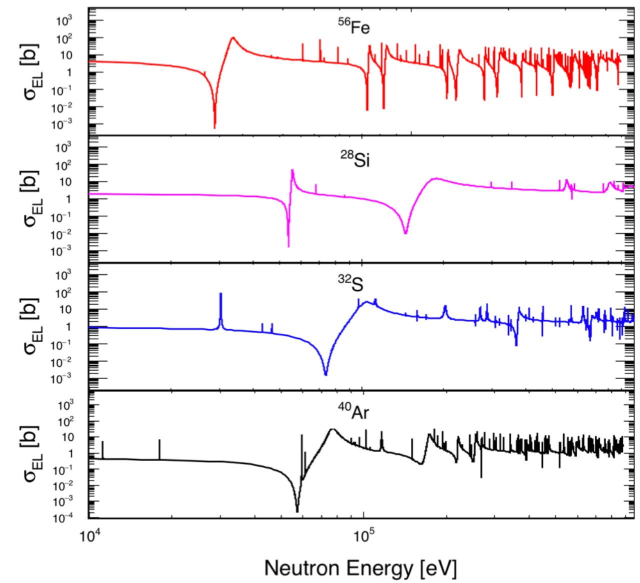
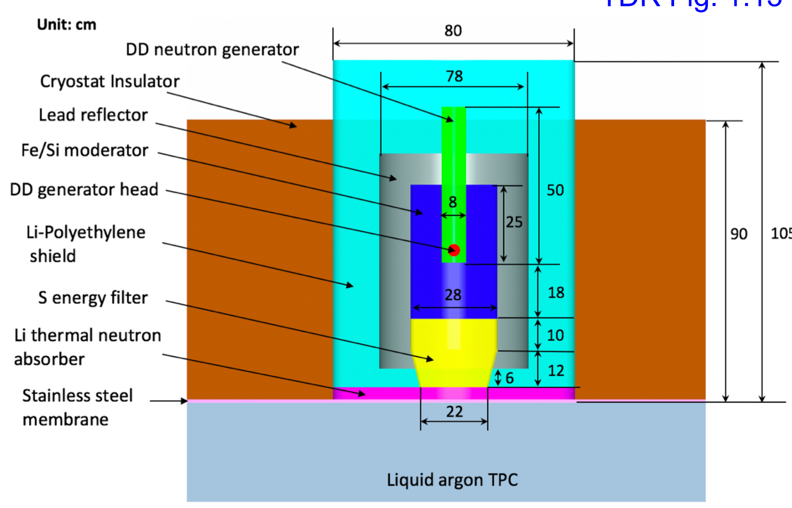
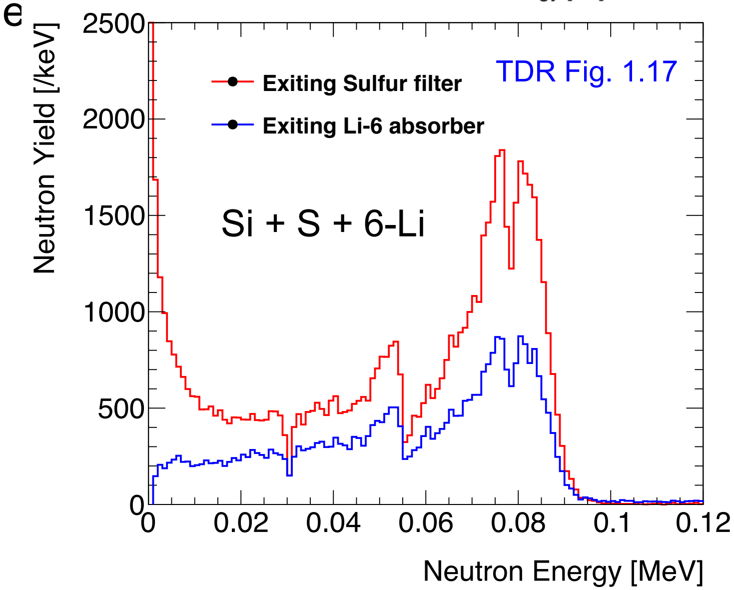
Moderator Performance

- Slow 2.5 MeV DD neutrons to 73 keV
  - Energy Pre-filter: Iron or Silicon (Silicon outperforms Iron)
  - Energy filter: Sulfur → 73 keV neutrons selected
  - Thermal neutron absorber: 6-Li → significantly reduce thermal neutron flux
  - 0.13% initial neutrons are captured in TPC
- The spectrum of the moderated neutrons is used as an input of the neutron simulation
- Risk: Existence of 57 keV anti-resonance to be verifie at Los Alamos Lab



TDR Fig. 1.13

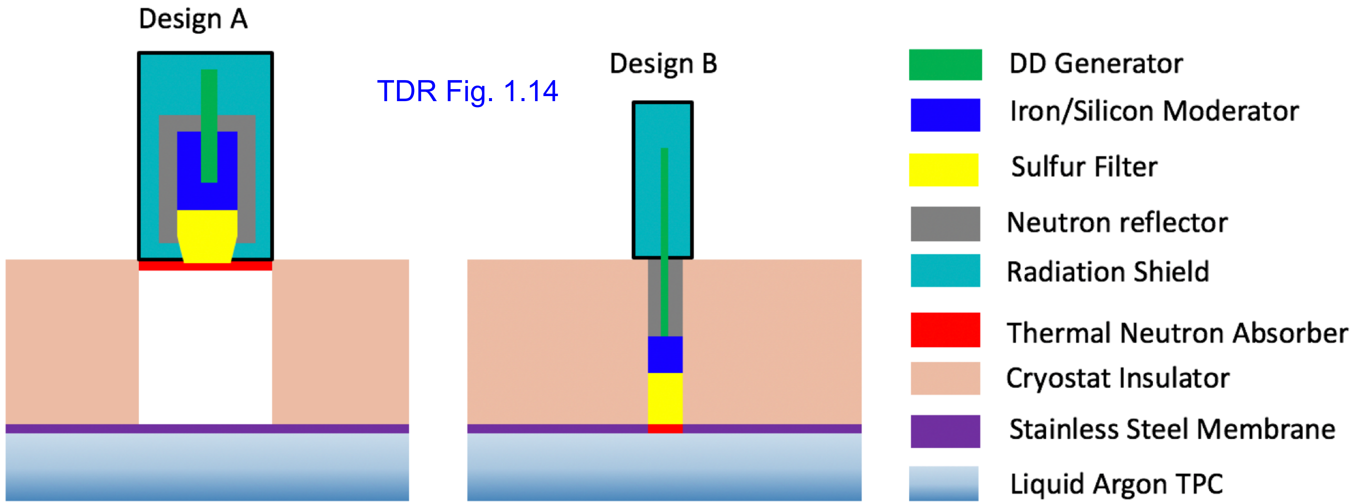




TDR Fig. 1.17

PNS Design and Location

- Two basic designs are currently written into the TDR
  - **Design A**: Large format PNS fully shielded; require large injection ports (e.g. manhole); can be placed inside the port
  - **Design B**: Small format PNS to be placed inside the 25 cm feedthrough ports
- Current plan is to deploy two large sources at the human access port (manhole) locations, and one small movable source on top at the center of the cryostat using the feedthrough ports
- Risk: neutrons injected from the corner manholes can't reach the middle of the TPC. The small format source can compensate the missing coverage

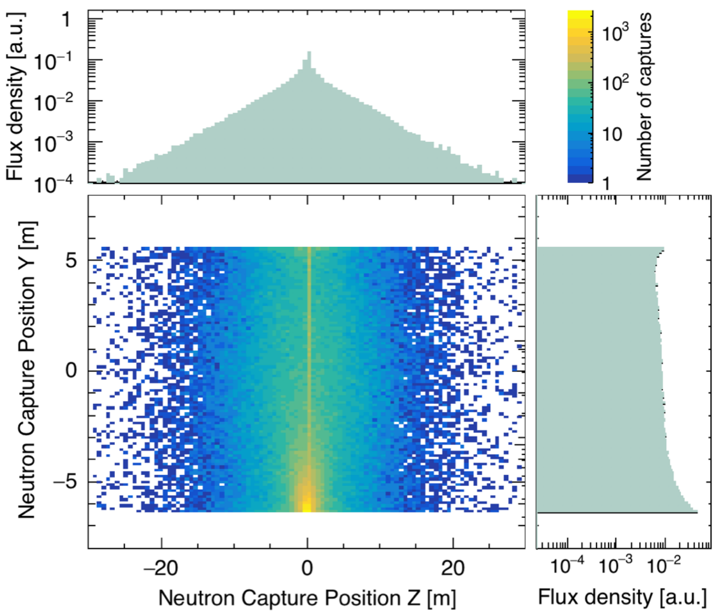


ProtoDUNE manhole interface: TDR Fig. 1.15

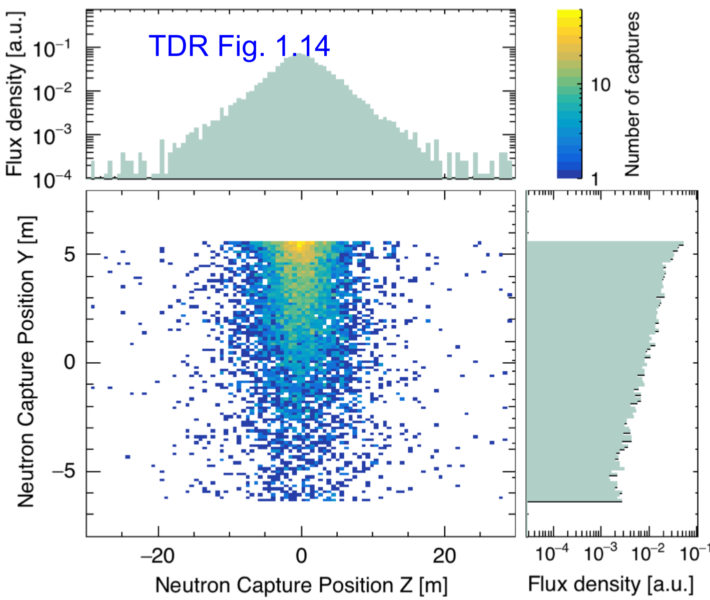
Neutron Capture in 10kt TPC

- Ideally, we want to inject 57 keV neutrons. Realistically, moderated 73 keV neutrons are injected.
- One neutron source can cover half the TPC
- The neutron capture position depends on the scattering length that will be measured by the proposed ARTIE experiment at LANL.

Side view of neutron capture position
Ideal case: pure 57 keV neutrons



Side view of neutron capture position
Realistic case: moderated neutrons around 73 keV



Data Volume Estimate

- The DAQ will be triggered by the DD generator pulses. The data size is simply **6.22 GB times the total number trigger pulses**
- Typically, a commercial DD neutron generator produces $10^5 – 10^8$ neutrons/pulse, depending on the pulse width
- TDR assumptions for evaluation of the data size:
  1) **Assume 10^6 neutrons per 100 μs DD pulse** → ideal assumption, achievable with lab DD generators but challenging for commercial devices
  2) Assume that **1000 neutron captures are needed for every m^3** → need 6×10^6 neutron captures in total for a 10 kt TPC
  3) Assume that neutron capture positions are uniform inside the TPC
  4) Assume **0.13%** initial DD neutrons captured inside TPC

$$2300\ Pulses \times 1.5\ \text{Bytes} \times 2\ \text{MHz} \times 5.4\ \text{ms} \times 384000\ \text{channels} = 14\ \text{TB/run}. \qquad (1.2)$$

- We plan to run the neutron source calibration every two months, so 84 TB is expected per year → could be reduced to <30% with zero suppression

Risks

ARTIE @ LANL

Test @ Berkeley
Test @ ProtoDUNE

Better DD generator,
Wider pulse width

Design B neutron source using feedthroughs

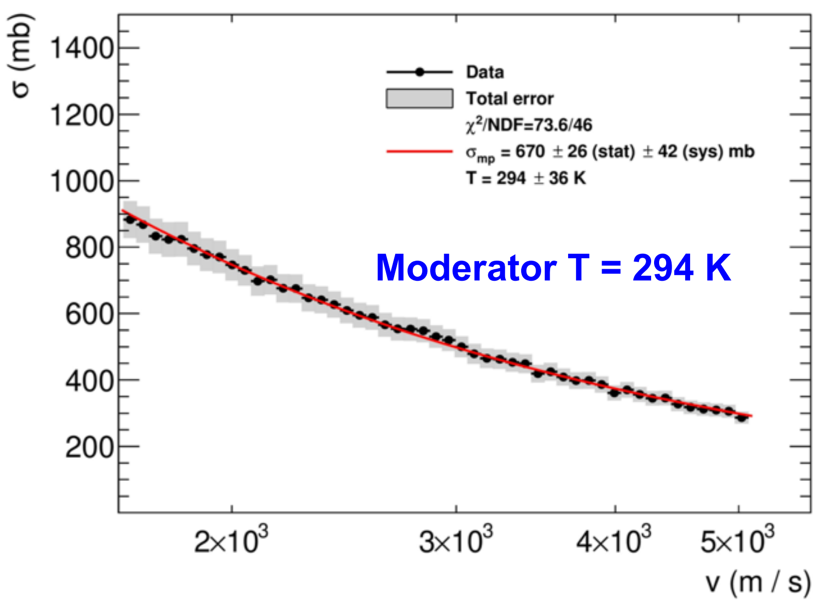
Table 1.10: Possible risk scenarios for the pulsed neutron source system along with mitigation strategies. The level of risk is indicated by letters "H", "M", and "L" corresponding to high, medium and low level risks.

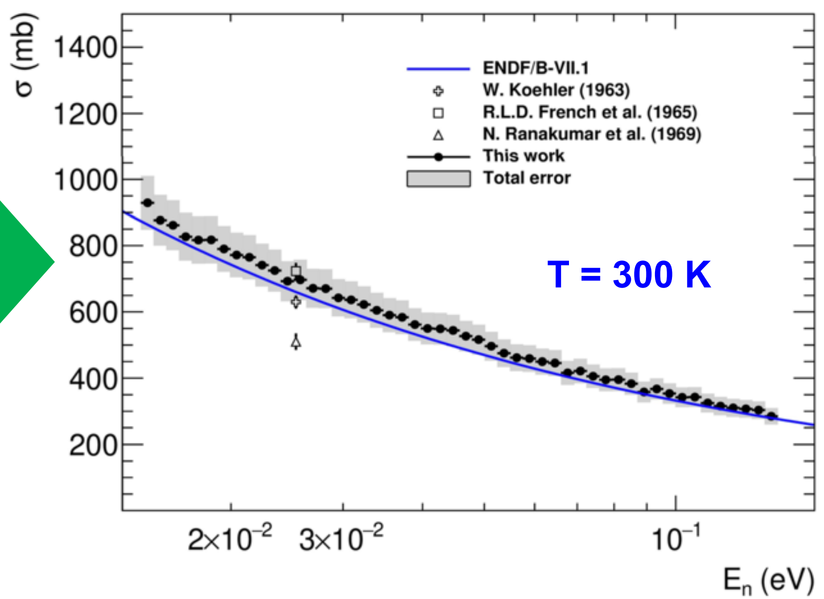
No.	Risk	Risk Level	Mitigation Strategy
6	The effective attenuation length of 57 keV neutrons in LAr turns out to be significantly smaller than 30 m.	M	A measurement of the transmission at this energy is being proposed at Los Alamos prior to the ProtoDUNE run. The ProtoDUNE run will also provide demonstration.
7	The neutron flux from the DD generator could activate the moderator and cryostat insulation.	L	Neutron activation studies of insulation material, and ProtoDUNE testing at neutron flux intensities and durations well above the run plan, as well as simulation studies done in collaboration with Background Task Force.
8	The neutron yield from DD generator is not high enough to provide sufficient neutron captures inside the TPC.	M	Investigation is being done on both commercially available and lab research DD generators; Placing the neutron source closer to the liquid argon TPC may increase the neutron yield by a factor of 6; Operating the DD generator with wider pulse is under consideration, which would require the photodetector system to provide the neutron capture time t_0. All of this will be tested in the ProtoDUNE-SP-II run.
9	Neutrons produced by the Pulsed Neutron Sources placed at the human access ports at the cryostat corners may not reach the center of the cryostat.	L	An alternative design (Design B in figure 1.13) with neutron source inside the calibration feedthrough ports (centrally located on the cryostat) is being studied. This small format neutron source would be light enough to be moved across different feedthrough ports, providing complementary coverage to the neutron sources at the human access port locations.

The ACED cross section result

- The ACED neutron capture cross section result has been submitted to PRD
- ACED will analyze the gamma spectrum from the neutron capture
- Result will update the neutron library in LArSoft for DUNE simulation
- For more detail, see http://if-docdb.fnal.gov/cgi-bin/ShowDocument?docid=419

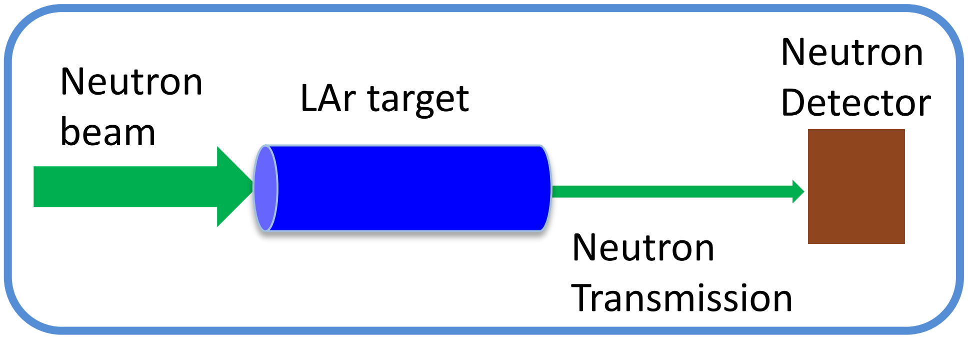
σ_{2200} = 673 ± 26 (stat.) ± 59 (sys.) mb



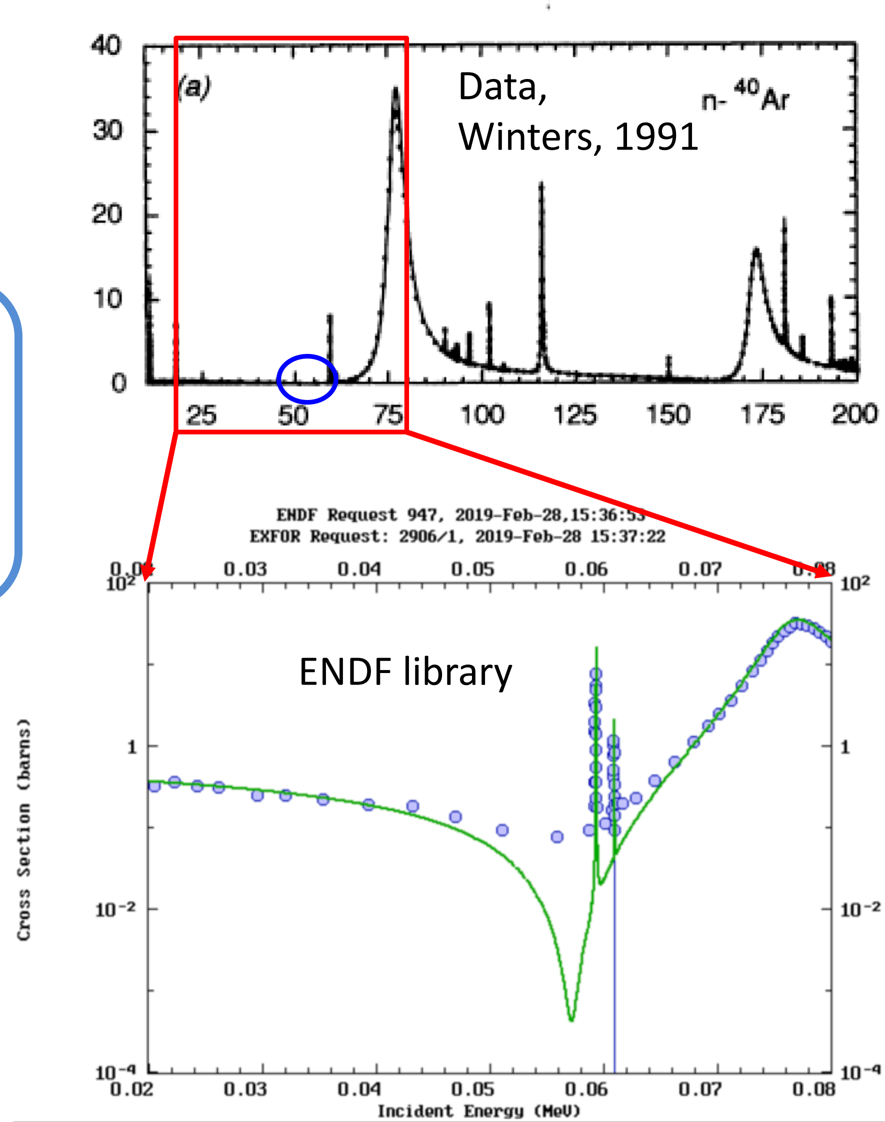


Next Measurement: ARTIE

We proposed the Argon Resonance Transmission Interaction Experiment (**ARTIE**) to Los Alamos National Laboratory to measure the neutron total cross-section in argon



- Previous Ar measurement around 57 keV was not sensitive enough to probe the resonance dip
- Measurement needs to be done with high precision in November 2019
- Opportunity at Lujan center at LANL (proposal submitted)



Simulation Status

- Neutron moderator simulation (UC Davis) is nearly completed. It needs to be experimentally verified by the moderator test with a DD generator
- Neutron transport simulation is being done by University of Pittsburgh (D. Naples and E. Harris)
- Background neutron simulation is being done by LIP (S. Andringa)
- Neutron capture simulation has just started at UC Davis (J. Wang)
- Need to take a look at the PhotoDetector simulation
- Calibration tree will be very helpful for simulation and analysis (thanks to J. Stock https://indico.fnal.gov/event/19948/)

Timeline in TDR

Table 1.13: Key calibration construction schedule milestones leading to commissioning the first FD module. (*) Schedule items related to the Radioactive Source Deployment System (RSDS) are to be considered pending system approval.

Milestone	Date (Month YYYY)
Laser systems design decision (including ionization laser, laser positioning and photoelectron laser)	January 2020
Laser systems design review	February 2020
PNS design decision	March 2020
PNS design review	April 2020
RSDS design review	May 2020
Start of module 0 component production for ProtoDUNE-II	April 2020
End of module 0 component production for ProtoDUNE-II	February 2021
Start of ProtoDUNE-SP-II installation	**March 2021**
production readiness review (PRR) dates	March 2022
South Dakota Logistics Warehouse available	**April 2022**
RSDS demonstration test at ProtoDUNE-SP-II (*)	April 2022
Start of Laser and PNS production	May 2022
Beneficial occupancy of cavern 1 and central utility cavern (CUC)	**October 2022**
End of PNS production	March 2023
End of Laser system production	July 2023
End of RSDS production (*)	August 2023
CUC counting room accessible	**April 2023**
Start assembly of calibration production units in the cavern	May 2023
Top of detector module #1 cryostat accessible	**January 2024**
Start installation and alignment of Laser boxes	May 2024
Start of detector module #1 TPC installation	**August 2024**
Start installation of Laser System periscopes	August 2024
Start installation of RSDS guide system (*)	August 2024
End of detector module #1 TPC installation	**May 2025**
Installation of RSDS purge-boxes (*)	May 2025
Installation of the PNS main components	June 2025

Summary

- 1^{st} TDR draft has completed on March 18, 2019
- Assumptions for the Pulsed Neutron Source:
  1) DD generator can produce 10^6 neutrons per pulse
  2) Need 1000 neutron captures per m^3 for calibration
  3) 13% initial neutrons are captured inside the TPC
  4) Deploy two large format sources using manholes and one small format source using feedthroughs
- 57 keV anti-resonance dip will be verified by ARTIE at LANL
- Simulations in LArSoft are expected to converge soon.