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Target Performance for 14 MeV Neutron Production at the Sandia Ion Beam Laboratory

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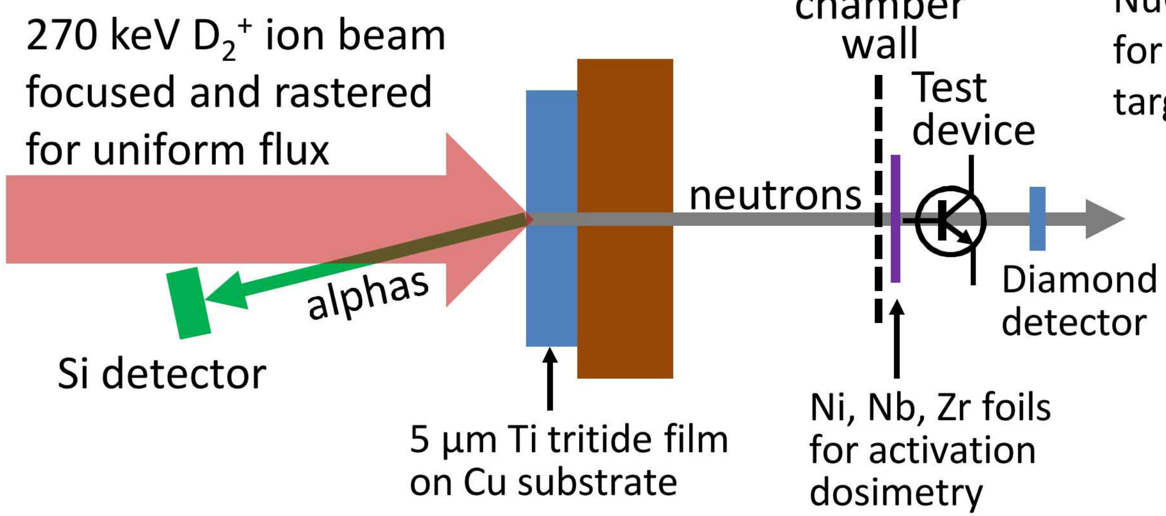
Introduction

- Displacement damage and ionization from energetic neutrons affect operation of electronics.
- Effects are greater for DT fusion neutrons than for fission neutrons (14 MeV vs ~ 1MeV).
- Tests are needed to characterize device response but few sources exist for 14 MeV neutrons.
- A facility for testing device response to 14 MeV neutrons
  has been developed at the Sandia Ion Beam Laboratory (IBL).
  Deuterium ion beam onto titanium tritide target.
- Neutron production rate decreases with time
  due to tritium loss from target by isotope exchange.

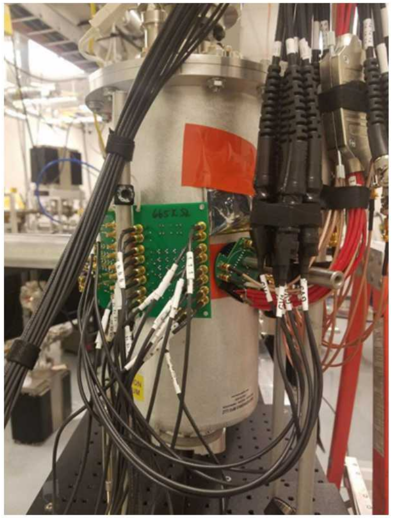
Outline:

- Description of system.
- Dosimetry
- Target lifetime optimization.
  DT isotope exchange with rapid mixing by thermal diffusion.
  Mixing model predicts target lifetime and neutron yield per target.
- Thin-film target design for extended lifetime and reduced tritium usage.
- New beamline/target chamber with smaller distance from n-source to test location.
- Examples of device tests

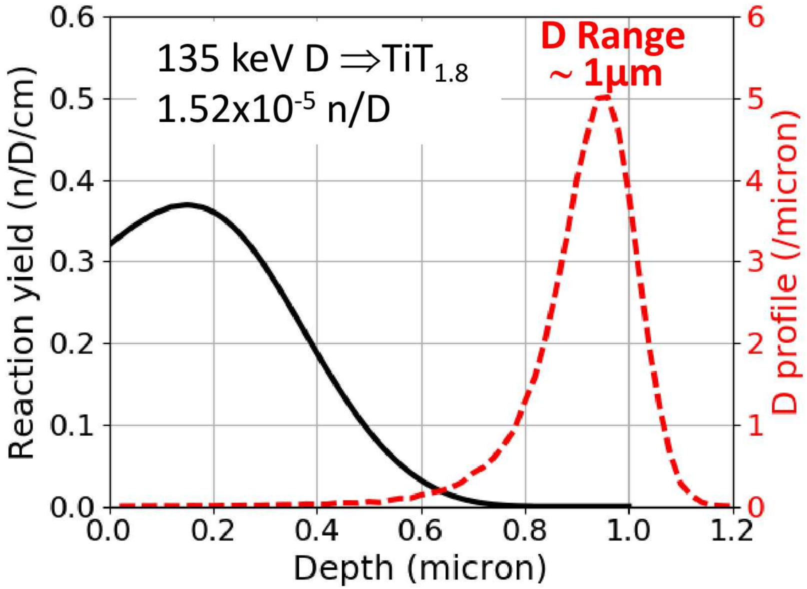
Test Setup



NuCAL test chamber designed for calibrating neutron monitors has target at center of 6" diameter chamber.



Calculated Reaction yield & D profile



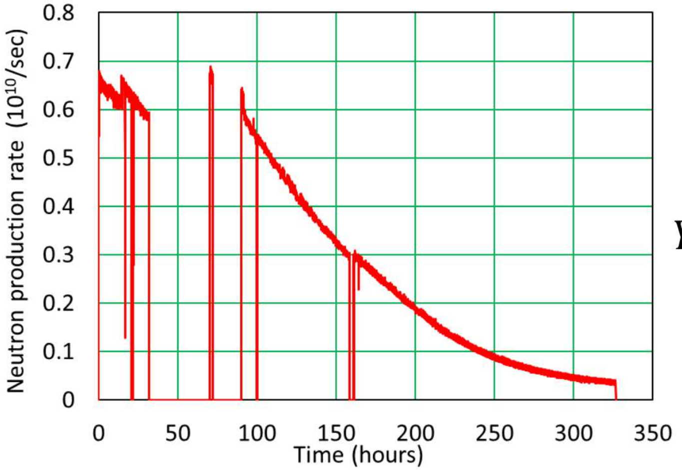
Neutron production rate:
$1.9x10^{14}$ n/Coulomb D_2^+
10^{10} n/s from 50µA beam

Neutron production rate & fluence determined by:

1. α yield (real-time)
2. Dosimetry foil activity (Total fluence)
3. Diamond detector (real-time)
4. DT reaction cross section, D beam current, T content (initial value)

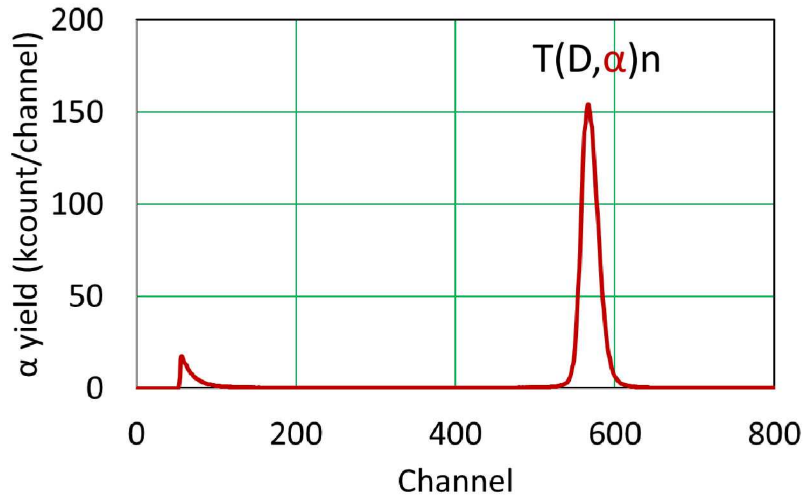
All agree

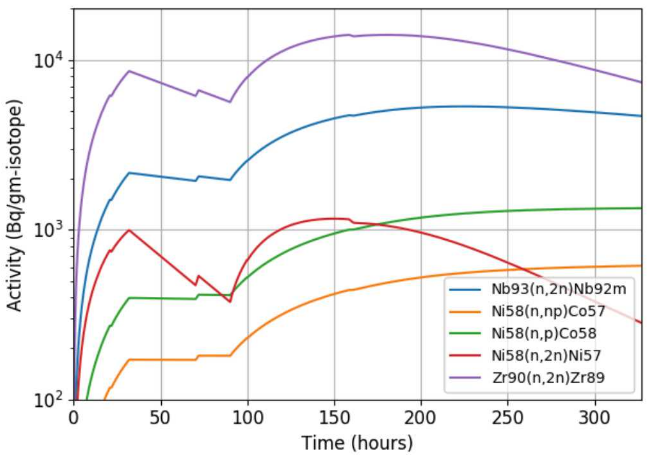
Dosimetry



Alpha yield measured by silicon detector gives neutron production vs time

$$Y_n = Y_\alpha \frac{4\pi}{\Omega} \left(\frac{\sigma_{cm}}{\sigma_{lab}}\right)_\alpha$$

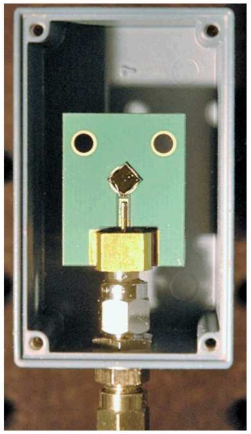


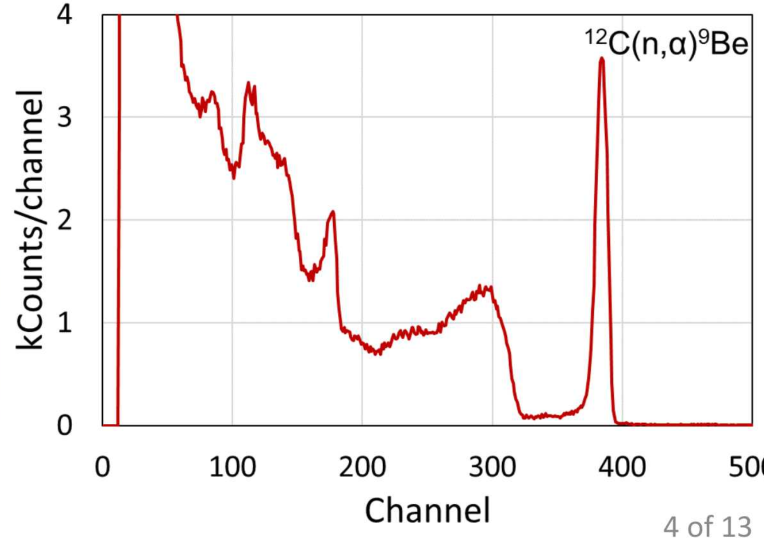


Foil activity measured by gamma counting agrees with values calculated from neutron flux within 12% for 5 activation reactions (ASTM E496).

	cx(b) @ E=14.1MeV	half life(days)
Nb93(n,2n)Nb92m	0.459	10.13
Ni58(n,np)Co57	0.582	271
Ni58(n,p)Co58	0.354	71
Ni58(n,2n)Ni57	0.0249	1.48
Zr90(n,2n)Zr89	0.627	3.27

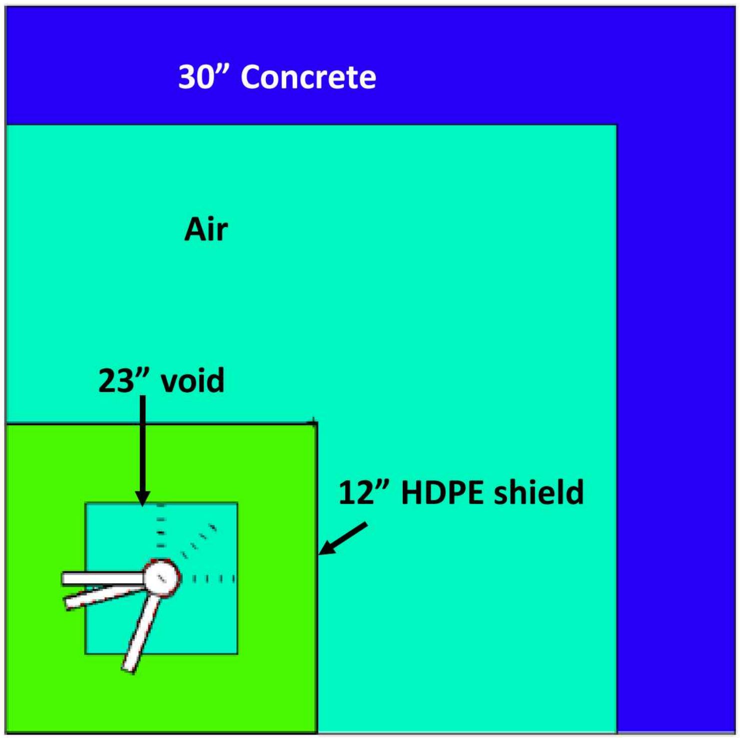
CVD diamond detector (4x4x0.5 mm) gives neutron flux vs time. Applied Diamond Inc.



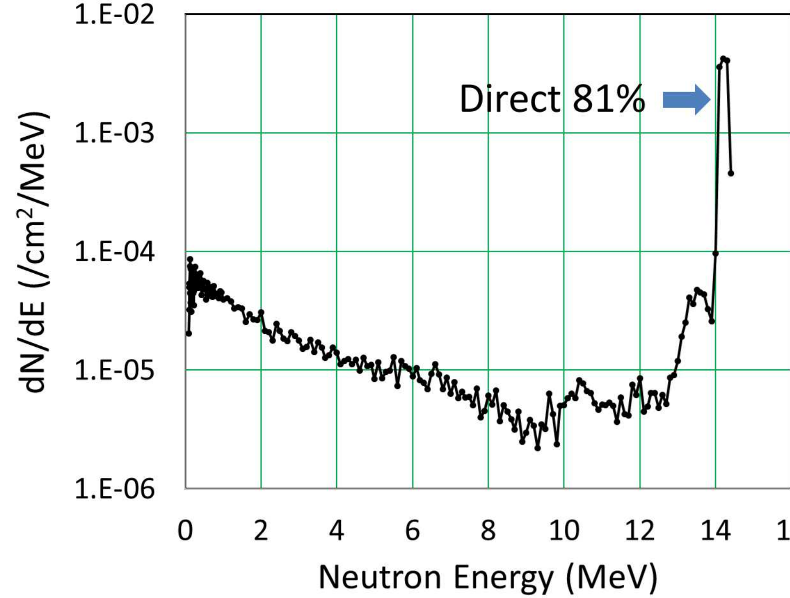


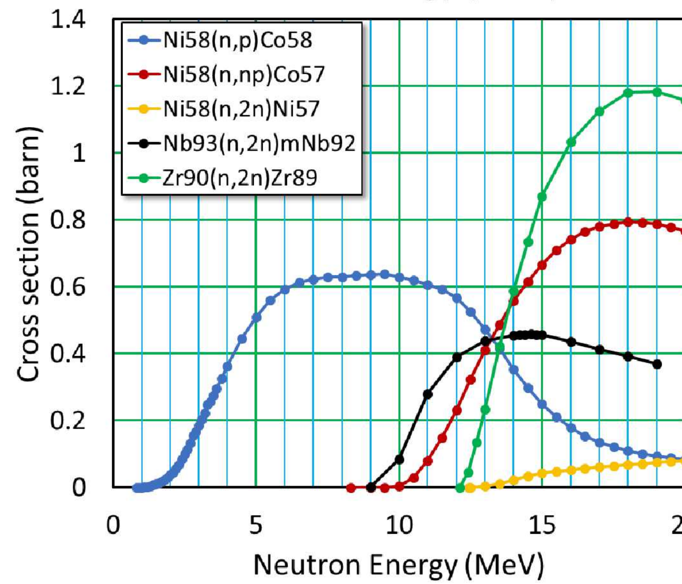
Effect of scattering on neutron energy spectrum from MCNP

Horizontal cross-section view



Neutron energy distribution
7.6 cm from source, 90° from D beam direction

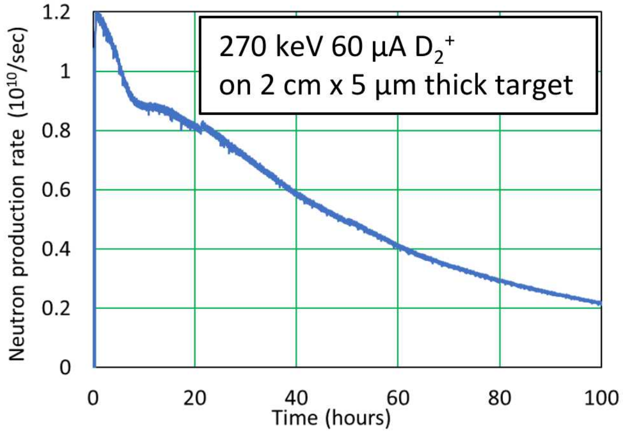




Scattered neutrons should have minimal effect on dosimetry foil activation and damage to devices

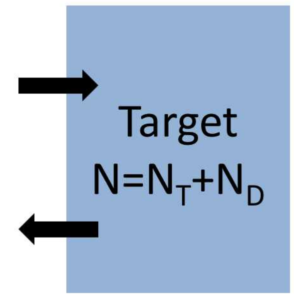
Isotope exchange model for target lifetime – thick target

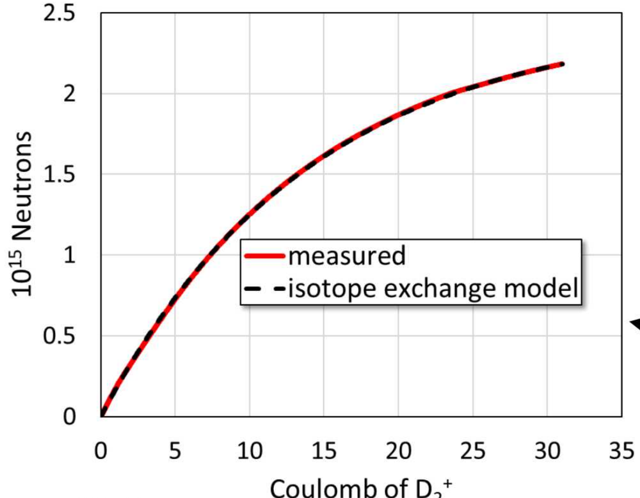
Neutron production rate decreases with time due to tritium loss from target.



ΔN_{Di}

$\Delta N_T = \Delta N_{Di}\,\frac{N_T}{N}$





- Implanted D mixes with T in target
- Total number of D+T atoms in target is constant determined by stoichiometry and volume.

$$N_T = N\,exp\left(-\frac{N_{Di}}{N}\right)$$

- Number of neutrons produced per incident D:

$$\frac{dN_n}{dN_{Di}} = \sigma\frac{N_T}{N} = \sigma\,exp\left(-\frac{N_{Di}}{N}\right)$$

- Number of neutrons produced:

$$N_n = \sigma\,N\left(1 - exp\left(-\frac{N_{Di}}{N}\right)\right)$$

Number of neutrons per target and target lifetime are determined by the amount of tritium undergoing exchange.

Target lifetime:

$N = 1.6\text{x}10^{20}$ atoms of T in target initially

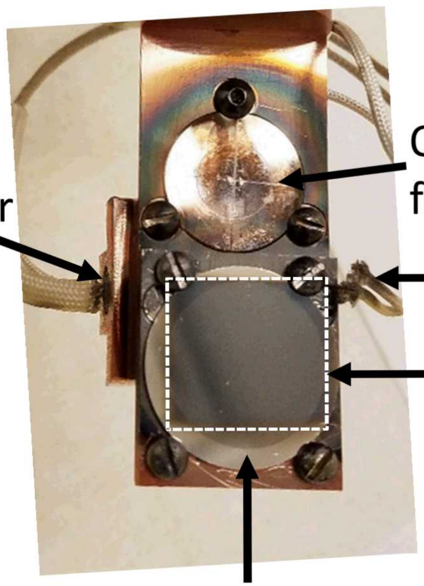
$q_eN/2 = 13$ Coulomb D_2^+

60 hours at 60 µA

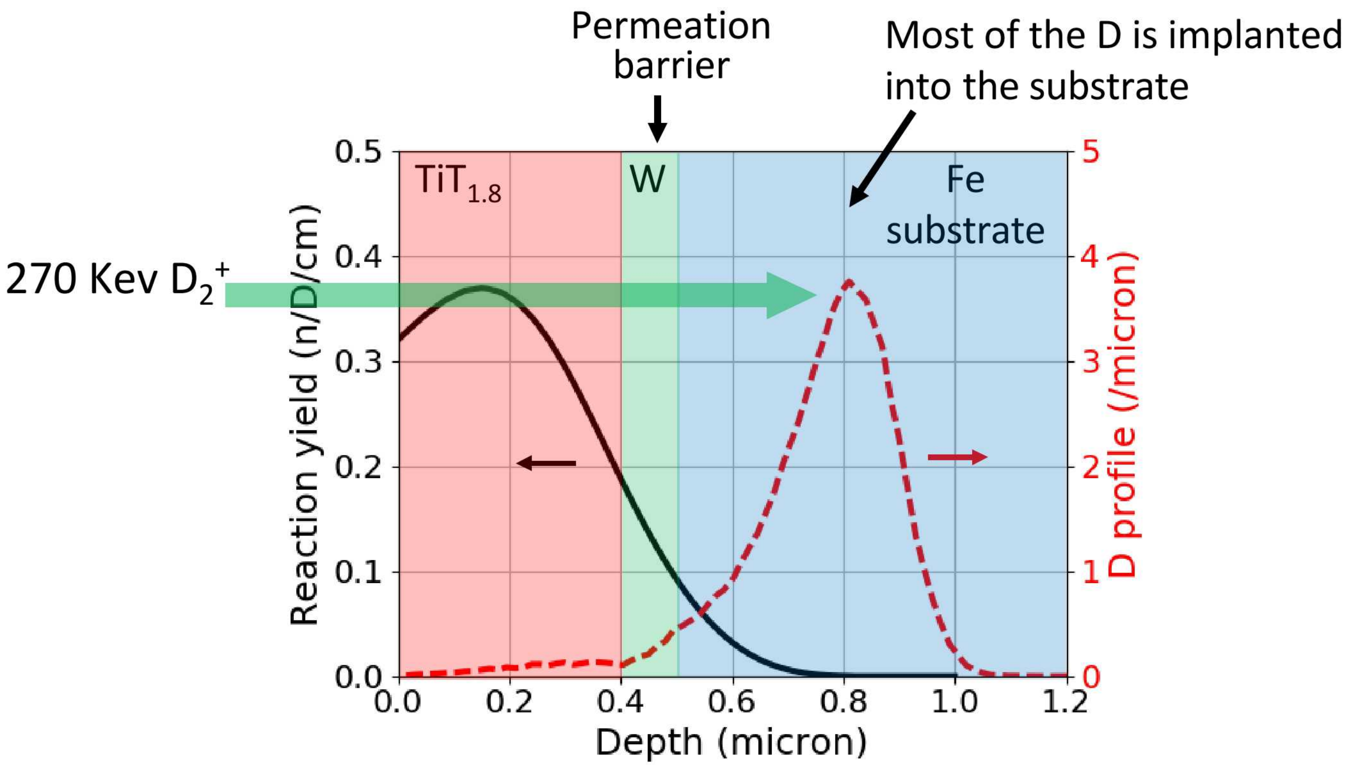
$\sigma\,N = 2.4\text{x}10^{15}$ neutrons per target

Target temperature is controlled at 150 °C during operation.

- At room temperature (T < 50 °C), time for DT mixing by thermal diffusion throughout 5 µm film is longer than the time for T loss by isotope exchange within 1 µm range of D. Concentration of T within 1 µm and neutron production rate decrease more quickly.
- At T=150 °C diffusion is 200x faster, DT mixing by thermal diffusion throughout 5 µm film is fast, Concentration of T within 1 µm and neutron production rate decrease more slowly, i.e. longer target lifetime. Also, thermal release of tritium is negligible at 150 °C.
- HDT profiles and film thickness measured by He^4 elastic recoil detection and Rutherford backscattering spectroscopy at the Sandia IBL confirm replacement of T by D.



Thin-film Target Development – FY18/19 LDRD



Purpose: Reduce tritium usage and increase target lifetime.

Incident D goes through the tritide film, stops in the substrate and diffuses into the substrate.

Barrier prevents permeation of implanted D into the tritide film.

Initial yield from thin target is 86% of thick target. 3% of incident D stops in 0.4 µm tritide.

12x less tritium, lower T loss, longer target lifetime and increased neutron yield per target.

SAND2017-0854 (OUO)

D transport in materials - requirements for thin target design

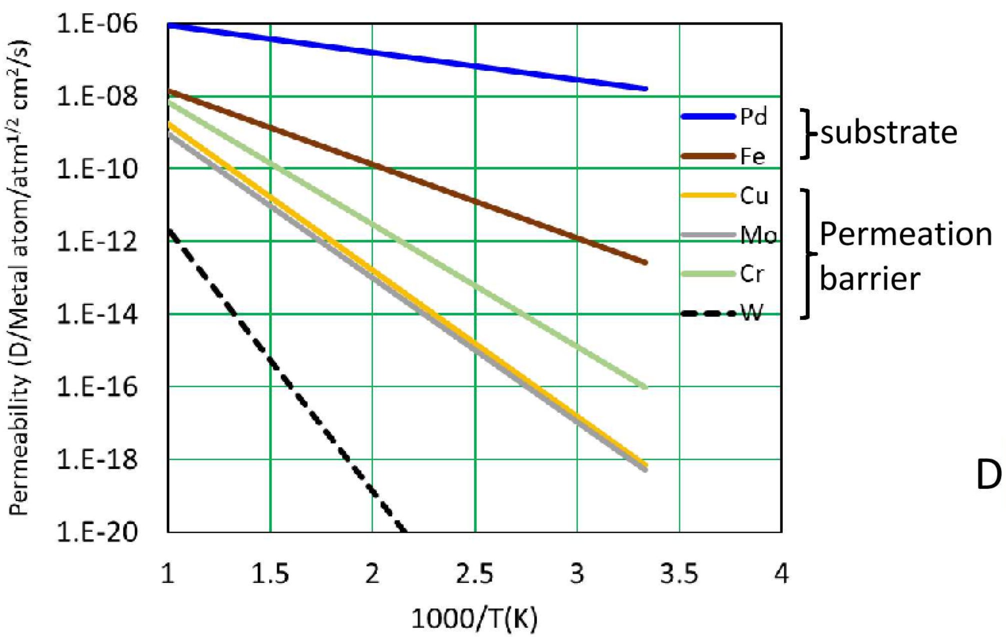
Substrate – High D permeation:

a) Good thermal conductivity (beam heating),

b) High D diffusivity.

c) Moderate D solubility, i.e.
not too low to avoid precipitation of implanted D
not too high to minimize tritium content from loading.

Candidates: **Fe, Pd**



Uncertainty in permeability:

- Small values at low T are extrapolated from measurements at higher T.
- Thin films may differ from bulk material.

Barrier – Low D permeation:

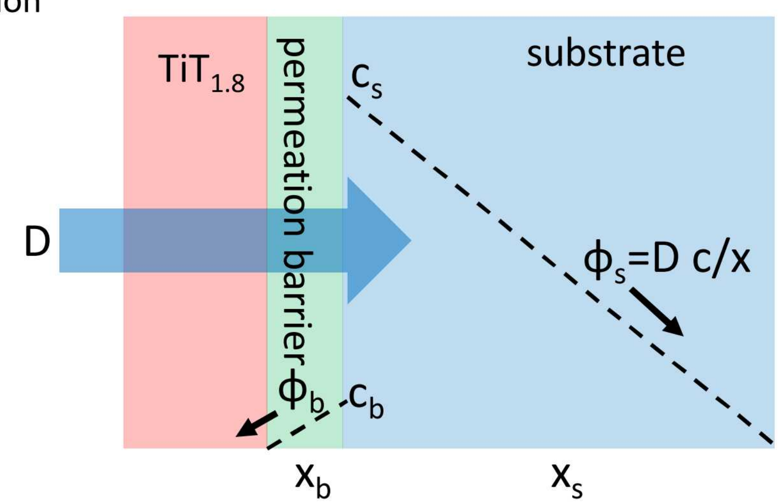
For target lifetime with 0.5 µm tritide same as for target with 5 µm tritide, D flux through the barrier layer must 10% of incident flux, i.e. 90% goes through the substrate:

$$\frac{\phi_b}{\phi_s} = \frac{\frac{c_b D_b}{x_b}}{\frac{c_s D_s}{x_s}} = \frac{x_s}{x_b}\frac{P_b}{P_s} < 0.1$$

With x_s=1 mm and x_b=0.1 µm:

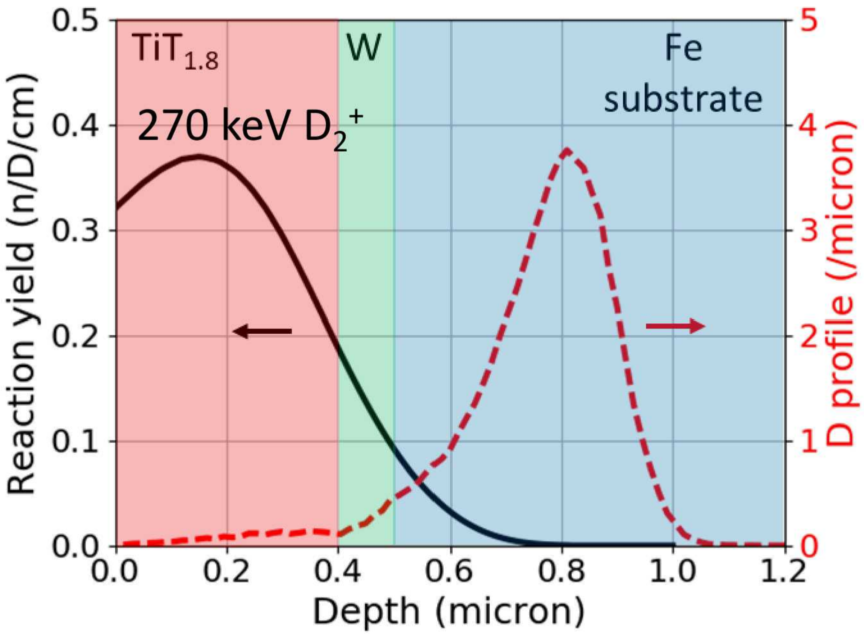
$$\frac{P_b}{P_s} < 10^{-5}$$

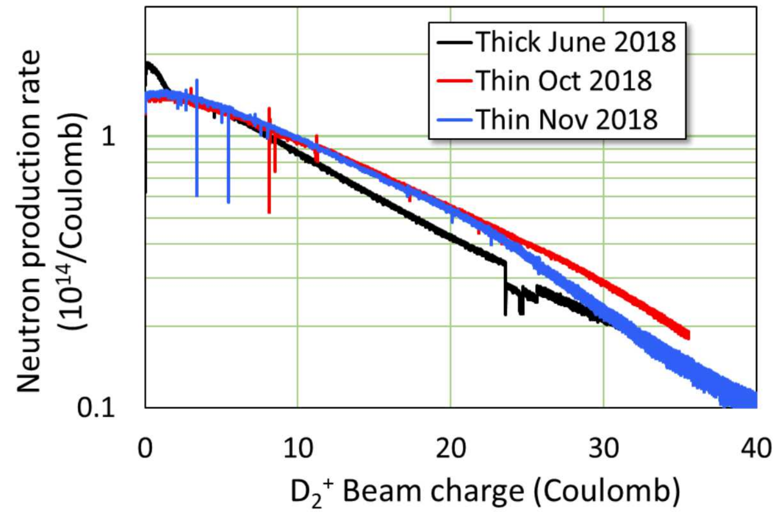
Candidates: **W, Mo, Cr,** Cu

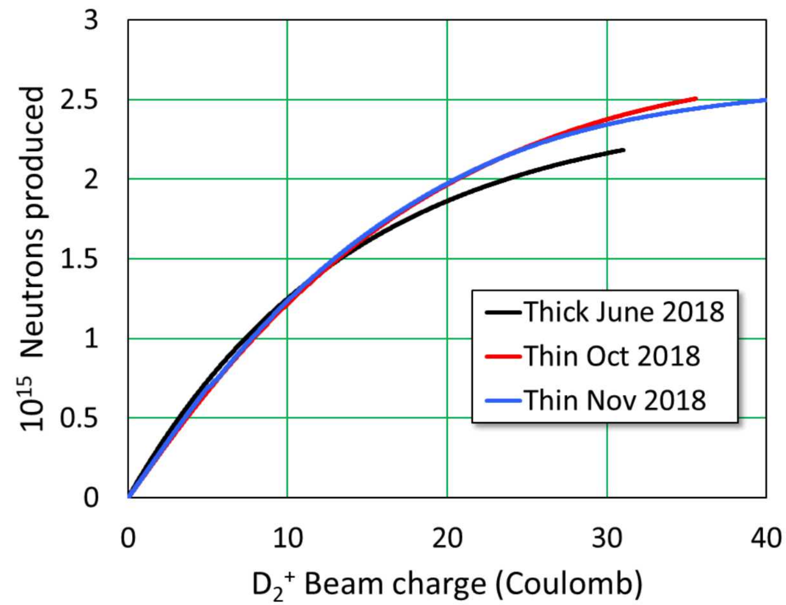


Dashed lines depict D concentration in steady-state.

Thin-film target performance







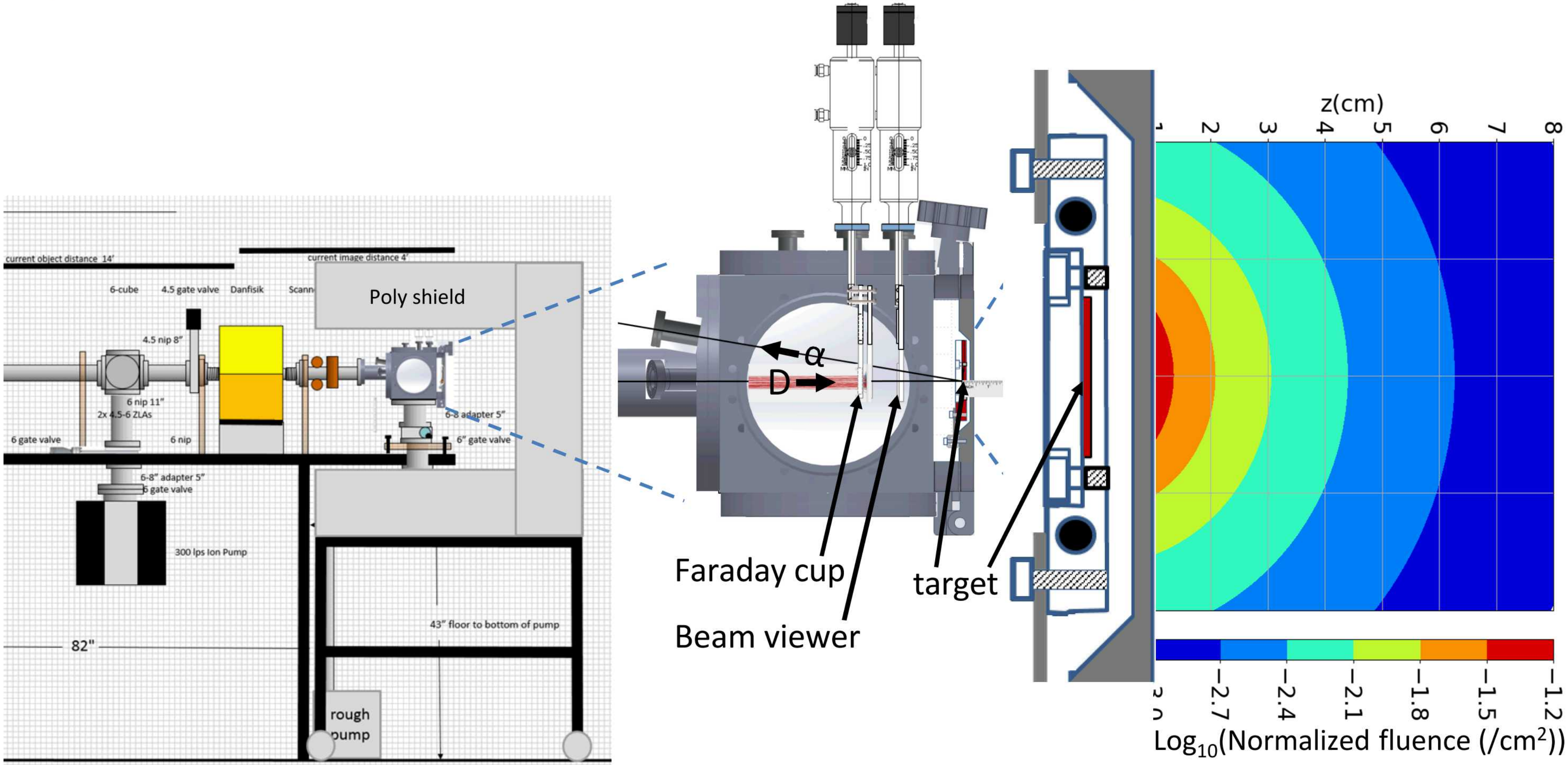
Result:

Neutron yield from thin-film Ti/W/Fe target 2.5×10^{15} was greater than from 5 µm thick-film target 2.2×10^{15} with 12x less tritium.

New beamline/test chamber for higher n-fluence at test location

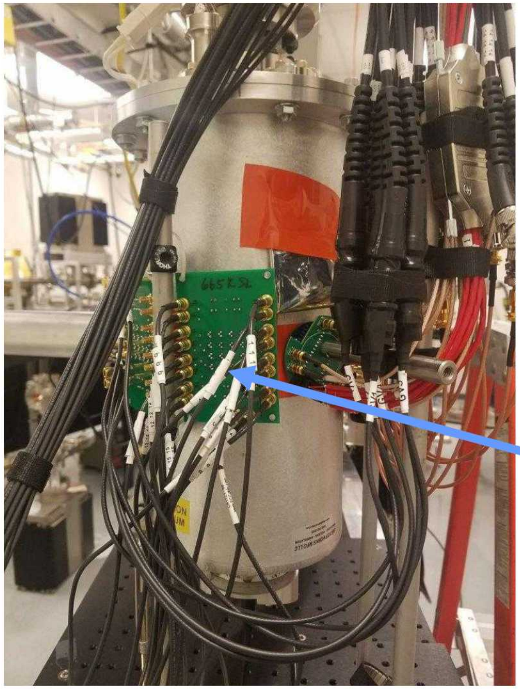
A new beamline and target chamber optimized for testing effects of 14 MeV neutrons on electronics is now in operation at the Sandia IBL.

Neutron fluence at test location increased ~40x to $>10^{14}/cm^2$ per target by decreasing distance from source to test location from 7.6 to 1 cm.



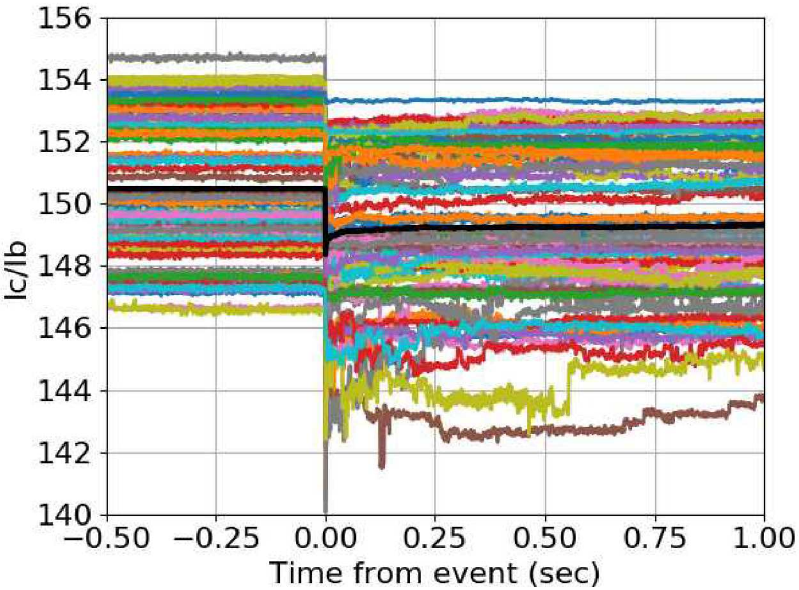
Examples of tests being done at Sandia

1. Gain change from displacement damage (HEART 2018) and HVB from single collision events in III-V HBTs.
2. Stuck bits and SEUs in highly-scaled CMOS SRAMs (N. Dodds, I.1 Friday)
3. Damage in Si Photodiodes (B. Aguire, I.2 Friday)
4. Photocurrent pulse amplitude in GaN HV diodes (in progress).
5. Qualification of COTS parts for NW systems.



16 Npn HBTs

Active & passive device test at the Sandia IBL



70 events in 16 devices from $2.7x10^{12}$ n/cm^2
Black curve is the average.

Displacement damage within small sensitive region of device reduces device gain.
Defect reactions (annealing) cause transient gain recovery.

Summary

- 14 MeV neutrons are being produced at the Sandia IBL for testing effects on electronics.
- Thick-film targets produce > 2×10^{15} neutrons/target with an initial rate of $>10^{10}$/sec.
- Neutron production rate decreases with time due to tritium loss from target by isotope exchange with implanted deuterium. Target life scales with the quantity of tritium, agrees with mixing model. Target temperature of 150 °C needed for full lifetime from 5 μm thick titanium tritide film.
- New thin-film target design with permeation barrier for longer life with less tritium has been developed.
- New beamline/target chamber provides higher neutron flux (~$5 \times 10^{8}/cm^2/s$) and fluence ($10^{14}/cm^2$/target) at test location.
- This new facility is in use for evaluation and qualification of device response to 14 MeV neutrons.