Neutron Generator Real-Time Control System Using Embedded Detectors To Replace Radioisotope Sources

TD-04

TECHNOLOGIES AND CONCEPTS FOR ACTIVE INTERROGATION 1

MAY 21ST, 10.30 - 11.30 AM PDT

PRESENTED BY: BRIAN E. JURCZYK, PRESIDENT

About Starfire Industries LLC

Champaign, IL USA (near the University of Illinois)

- ~35 employees, including 6 PhDs
- 14,000 ft^2 engineering, lab/test and production space
- Vertical integration from R&D, manufacturing, applications testing and support

<u>**Particle Accelerator Solutions:**</u>

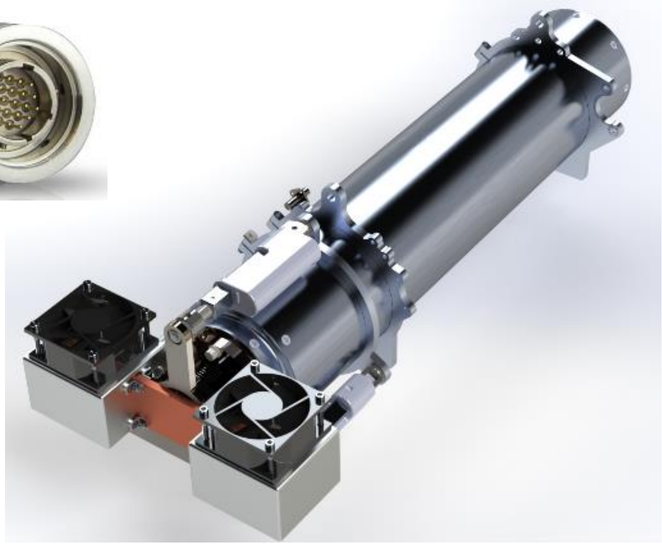
- **nGen® portable neutron generators**
- **Centurion® ultra-compact MeV particle accelerators**

<u>Plasma Processing Solutions:</u>

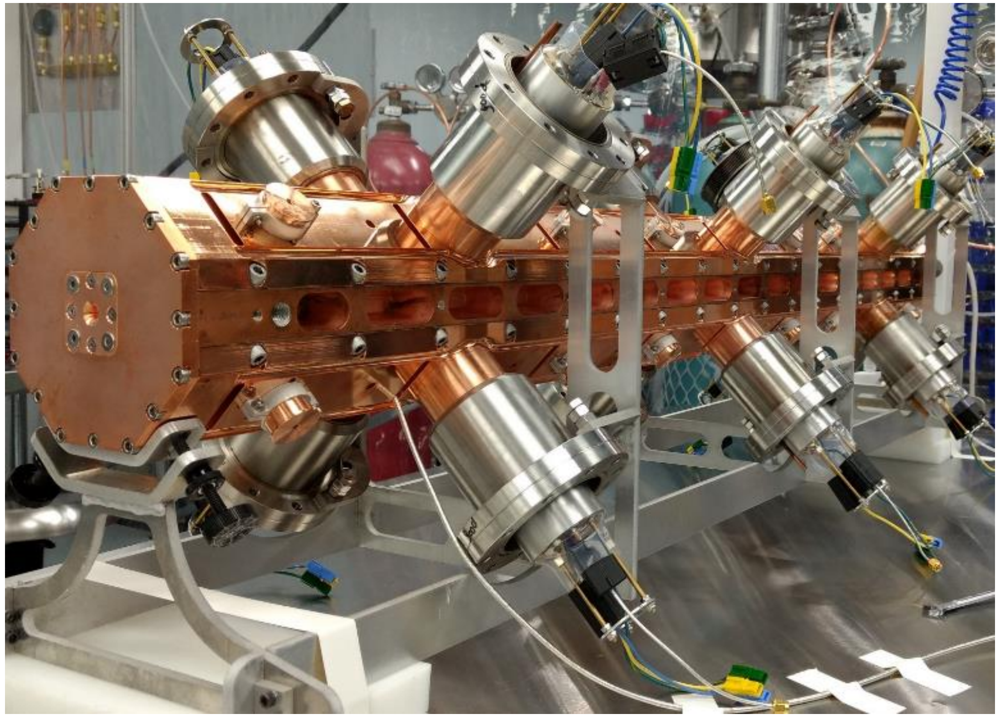
- IMPULSE® pulsed power modules for sputter/etch
- RADION™ microwave plasma sources for PECVD/etch

Two Business Groups Within One Organization
Products on 6 Continents!
Patent Portfolio Across Products

Particle Accelerator Solutions



Patented nGen®
Portable Sealed
Neutron Generators
With "End-Snout"



Centurion®
Patented Ultra-Compact RFQ LINACs
For Protons & Deuterons

Problem Statement

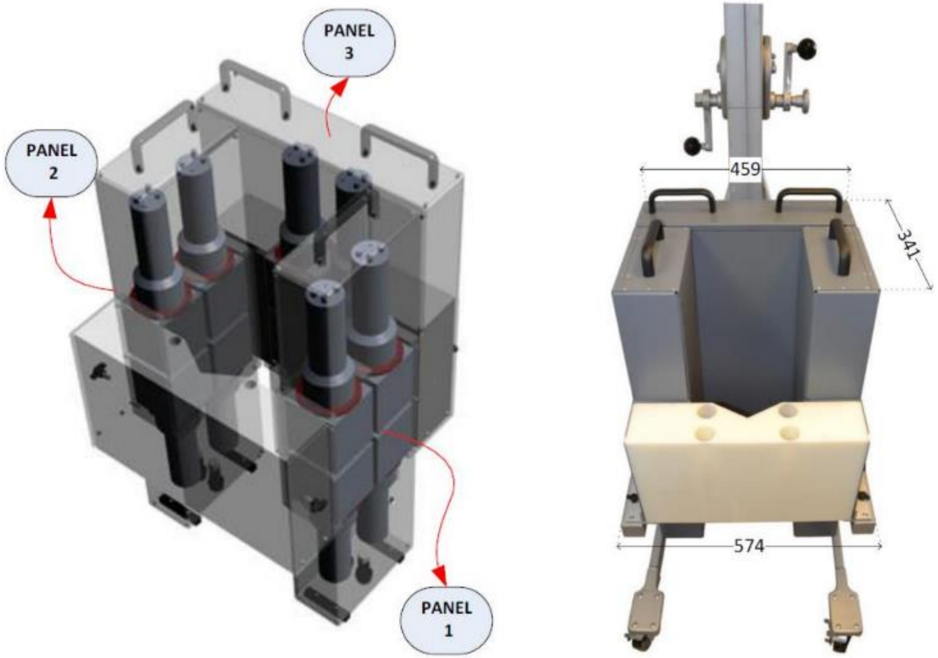
Goal: Replace Am-Li radioisotope sources used for nuclear safeguards and treaty verification processes with D-D fusion

Hypothesis: 2.5-MeV neutrons from the D-D fusion reaction are acceptably below the inelastic scattering threshold

Problem: Users employ algorithms that rely on the stochastic and continuous emission statistics inherent to radioisotopes to observe deviations from normal expected values.

Challenge: How to maintain steady neutron output that is well characterized and flat with continuous emission statistics at 1E5 to 1E6 n/s?

This Talk: We report on integrating RDT Domino® ^{6}Li-tiled detector into a module around an nGen®-350 DD generator and real-time feedback control under low output conditions



https://publications.anl.gov/anlpubs/2019/04/148938.pdf

https://www.mirion.com/products/jcc-51-active-well-neutron-coincidence-counter

Controlling Sealed Tubes Is Difficult

Inherent in these electrical devices are **multiple factors and time constants** that affect the neutron output including:

- Temperature (ambient, internal, target, electronics)
- Tube pressure
- Voltage fluctuations, current transients
- Material aging within the tube, target wear
- Erosion of materials, contamination
- Electronics wear, component drift with time
- Thermal mass, inertias
- Neutron emission cross section vs. voltage
- Desired operation modes (e.g. pulsed vs. continuous)
- Many others…

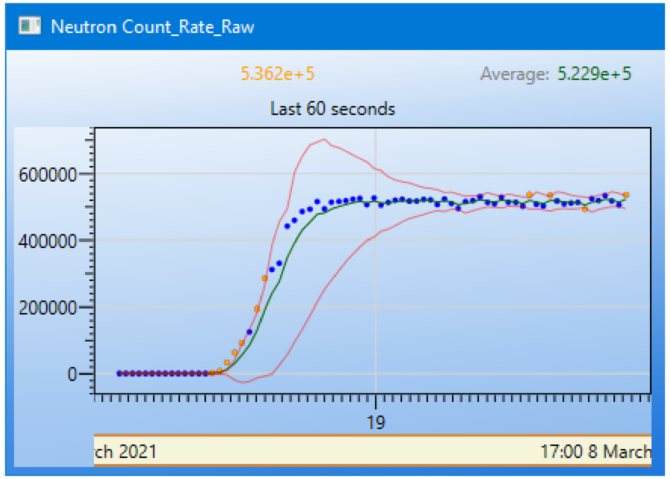
Our Challenge

Dynamic response control to maintain emission within certain stability parameters over the range of 1E5—1E6 n/s

1) stabilization time within 60 seconds to the desired neutron emission rate,
2) **less than 10% relative standard deviation for neutron emission over a 1-second interval,**
3) **the number of neutrons emitted in successive intervals of 1 minute have a relative standard deviation less than 1%,**
4) the system operate for a minimum of 10 minutes for stabilized data acquisition, and
5) provide direct access to unmoderated 2.5MeV fast flux on axis for integration with active interrogation system.

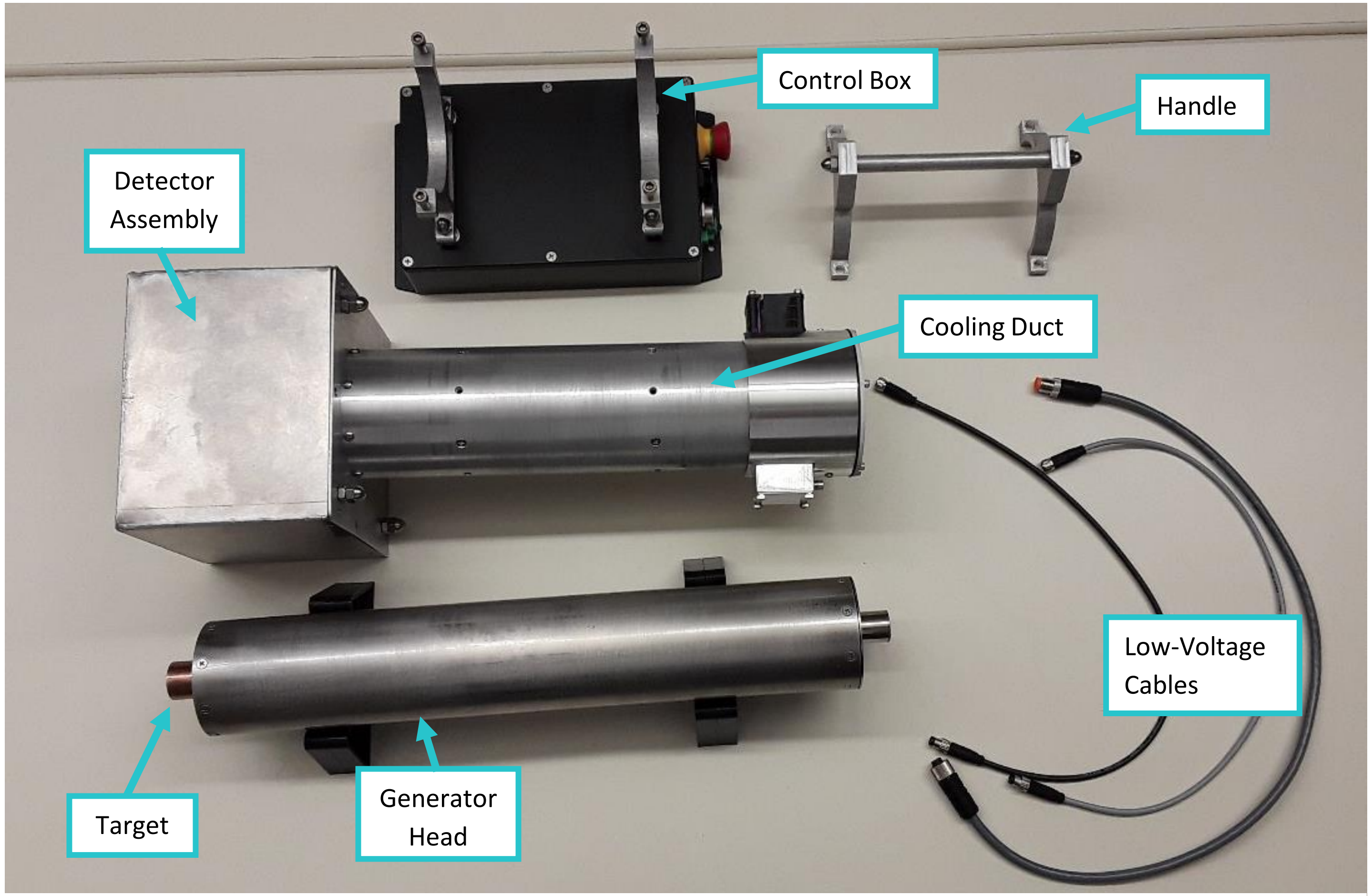
To obtain the counting statistics needed for 1-sec intervals at 1E5 n/s, we selected RDT thermal tiles

RDT Domino® Solid-State Tile Detectors
https://radectech.com/msnd_technology



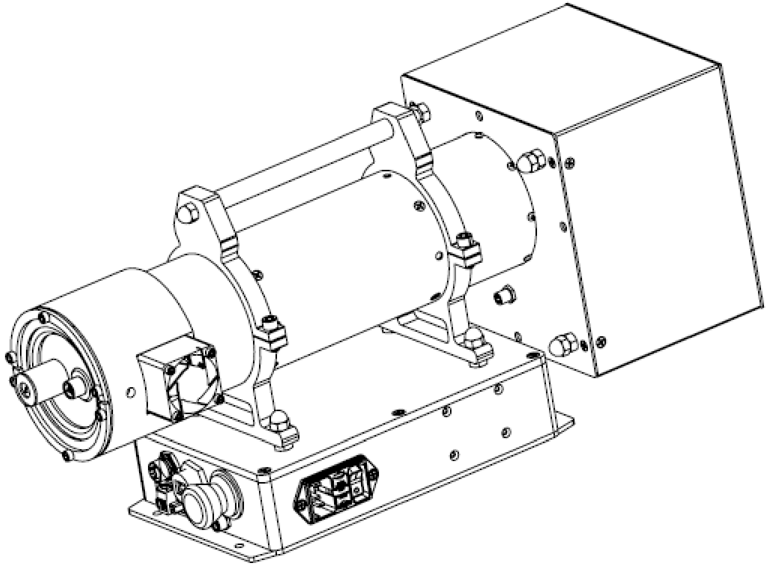
Example: Ramp and stabilization within 60 seconds

nGen®-350

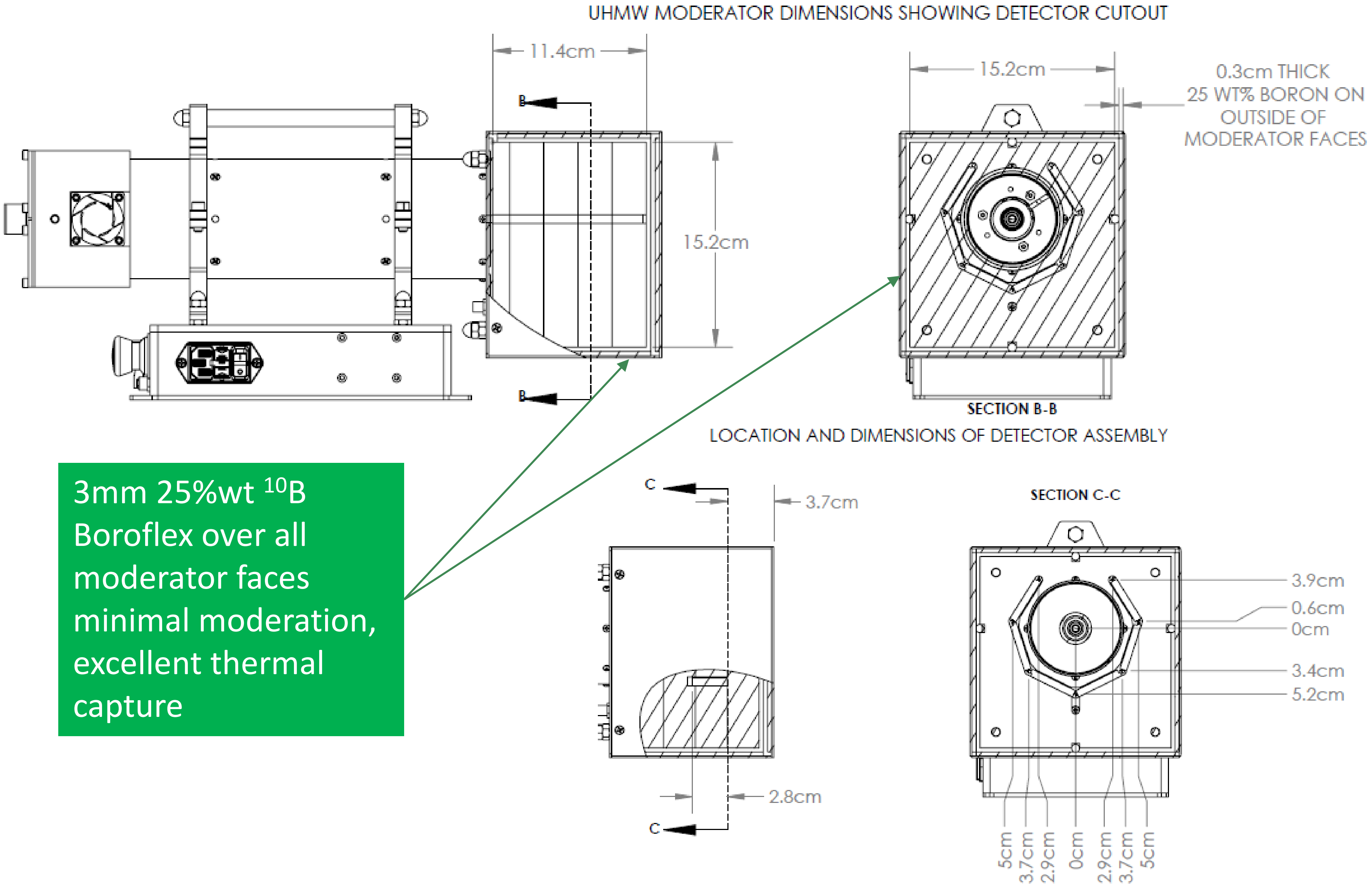


We built a small shieled moderator to thermalize back-streaming neutrons in a small well with embedded RDT detectors…while still allowing the fast forward-flux to exit

Parameter	nGen® 350
Entire System Weight	**11.45 kg**
Control Box Weight	2.25 kg
Detector Module Weight	3.50 kg
Generator Head Weight	5.70 kg
Generator Length	49.5 cm
Generator Height	22.2 cm
Generator Width	16.8 cm

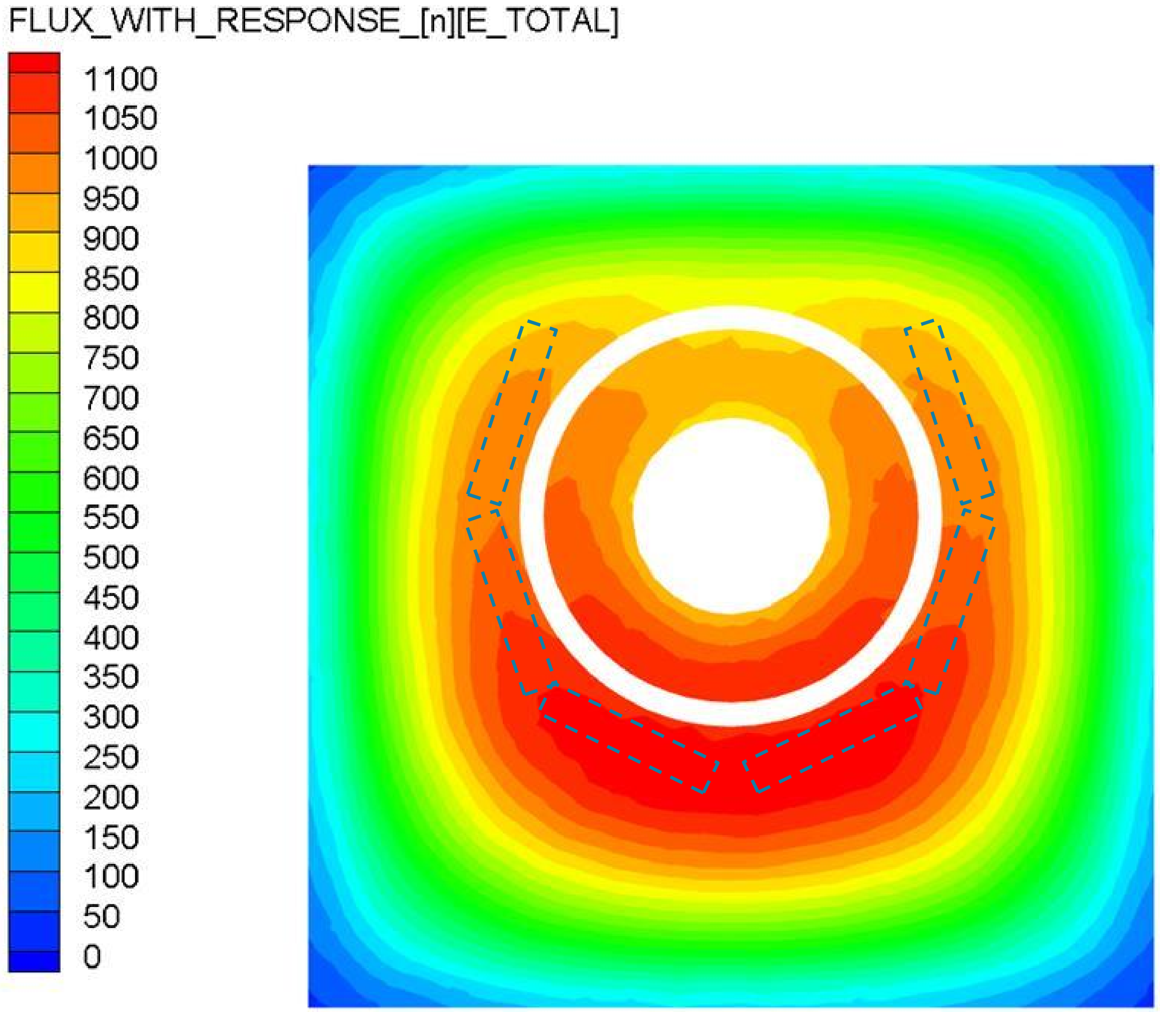


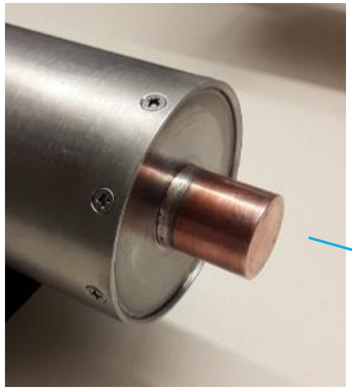
UHMWPE Moderator w/6 RDT Domino®



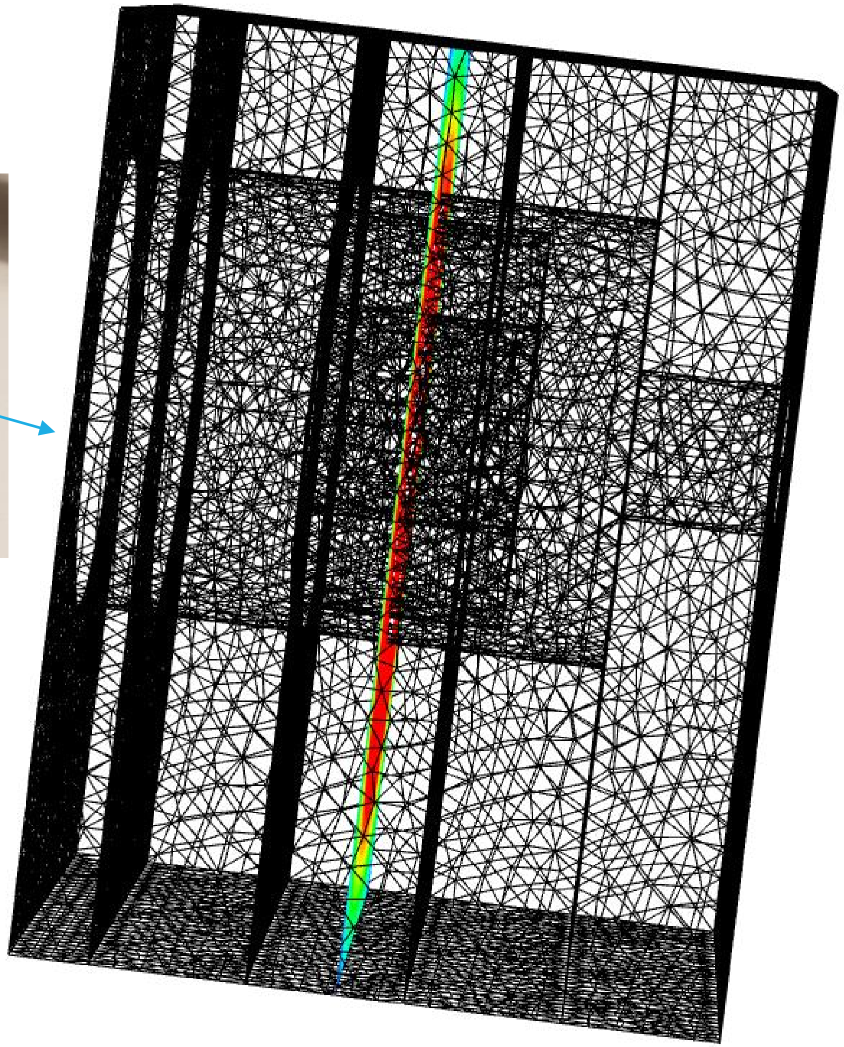
3mm 25%wt ^{10}B Boroflex over all moderator faces minimal moderation, excellent thermal capture

MNCP Modeling Response

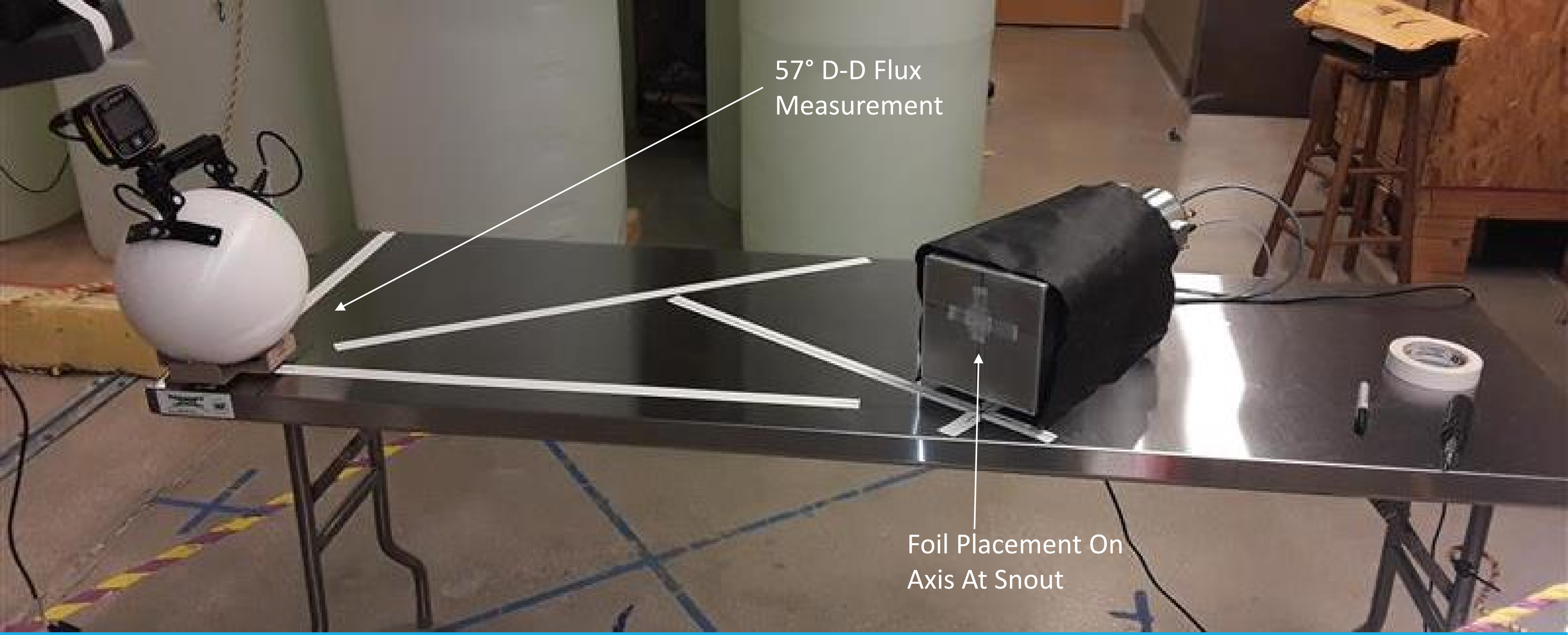




End-snout target slides in



Initial system initially modeled needed 4 lower RDT detectors, but we increased to 6 after trials



Foil & REMBALL Setup for 2.5e6 DD n/s calibration

Foil taped to exterior of aluminum housing, along the generator axis

REMBALL (9” [22.9cm], Ludlum model 30-4) positioned 1-m from source at 57° from generator axis

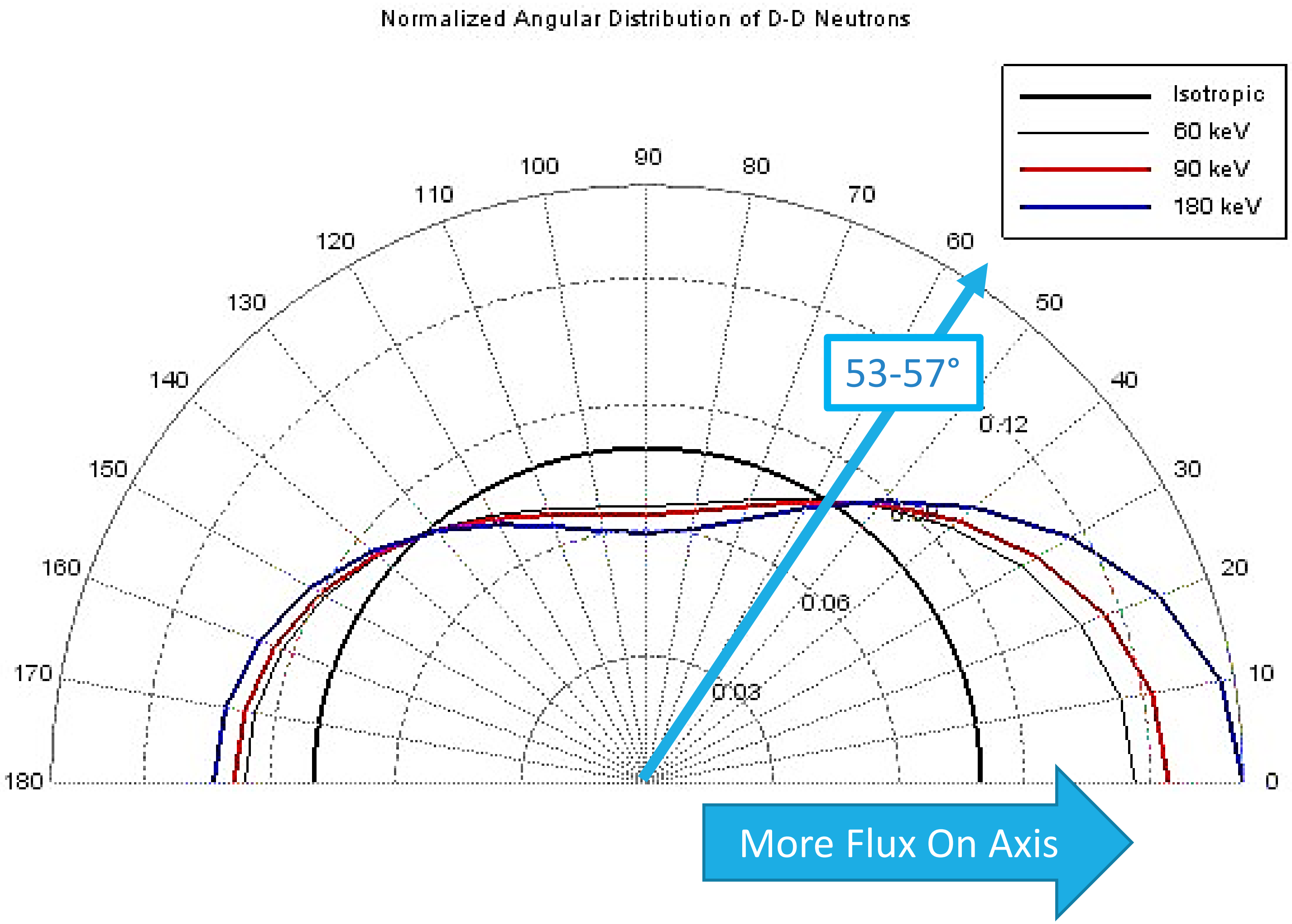
D-D Neutron Anisotropy

The D-D fusion reaction is highly anisotropic along the beam axis
- Higher flux [n/cm^{2}s] on 0°
- More than twice 90° flux

Calibration is difficult due to the energy-angle dependence

Around 53-57° the isotropic and normalized distributions up to 200keV are weighted equally
- Sampling flux here with a REM ball is an accurate measurement

At 1-m, unit recorded 2.5 mREM/hr averaged over 10 minutes
- 1mREM at 57° = 1e6 n/s into 4π str



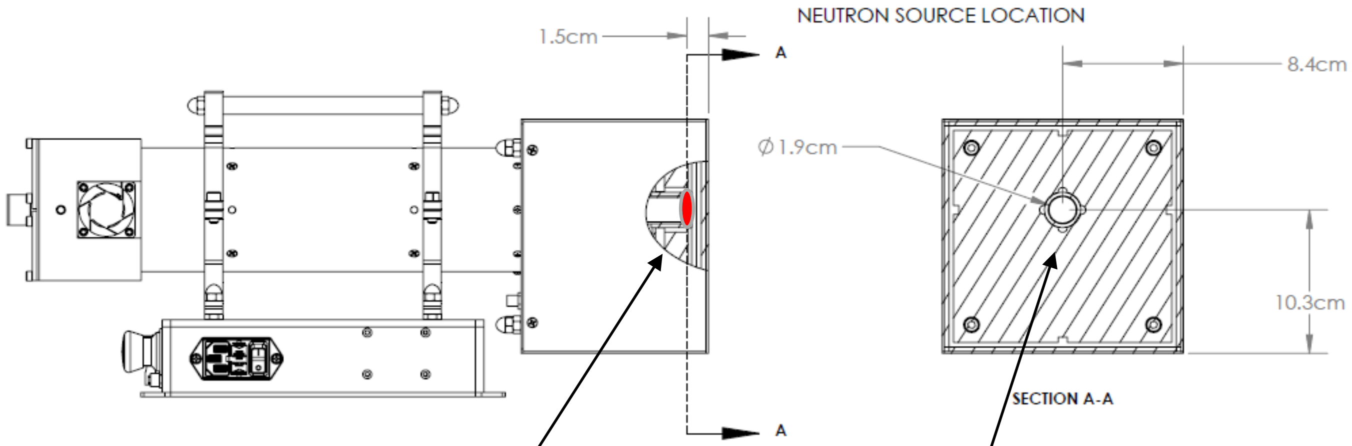
General Activation Foil Information

Approach

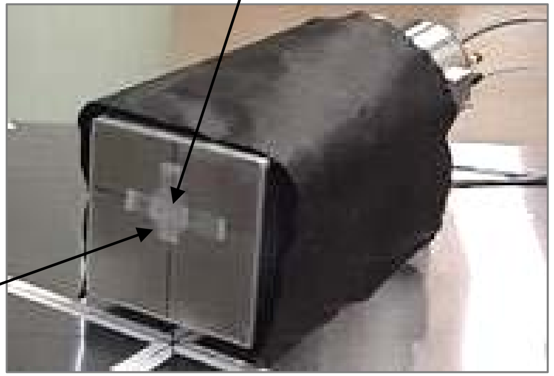
- Use $^{115}In(n,n')^{115m}In$ threshold reaction to directly measure fast neutron flux
- Measure activity of ^{115m}In using area under the curve of the gamma peak (336-keV)
- Reduced sensitivity to elastically scattered neutrons
- No sensitivity to moderated neutrons (<0.5 MeV)

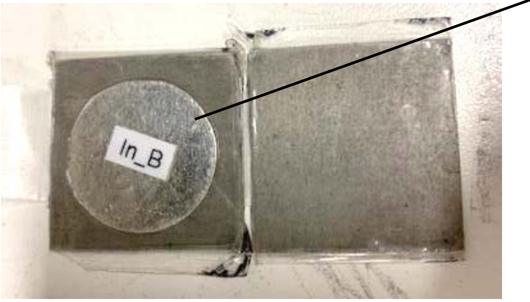
Hardware

- 25.4mm dia, 0.025mm thick indium foil (~1g)
- 0.51mm thick Cd cover (picture) to reduce $^{115}In(n,g)^{116m}In$ reactions
- 38x38mm $LaBr_3$ detector
- MCA (UCS-30)



End Snout Target





Indium Foil
w/Cd Cover
Taped To Front

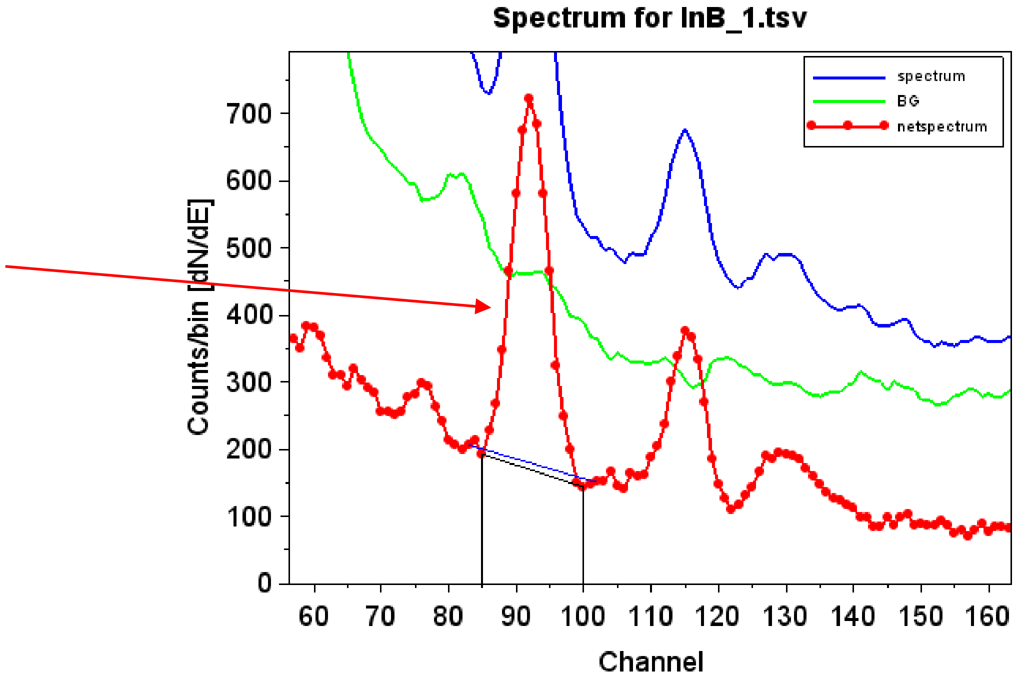
Activity Measurement

Process

- Mount foil (in line with target, 15.7mm on aluminum box exterior, on axis)
- Activate foil – usually for ~60min
- Transfer foil and mount directly on detector face
- Determine activity
  - Usually consecutive 1-hour collections
  - Remove background

Spectrum

- Peak around channel 93 is the 336-keV peak we are interested in
- Peak around channel 115 is one of many interfering peaks from (n,g) reactions
- Measure area under the curve after removing background
- First 1-hour of data



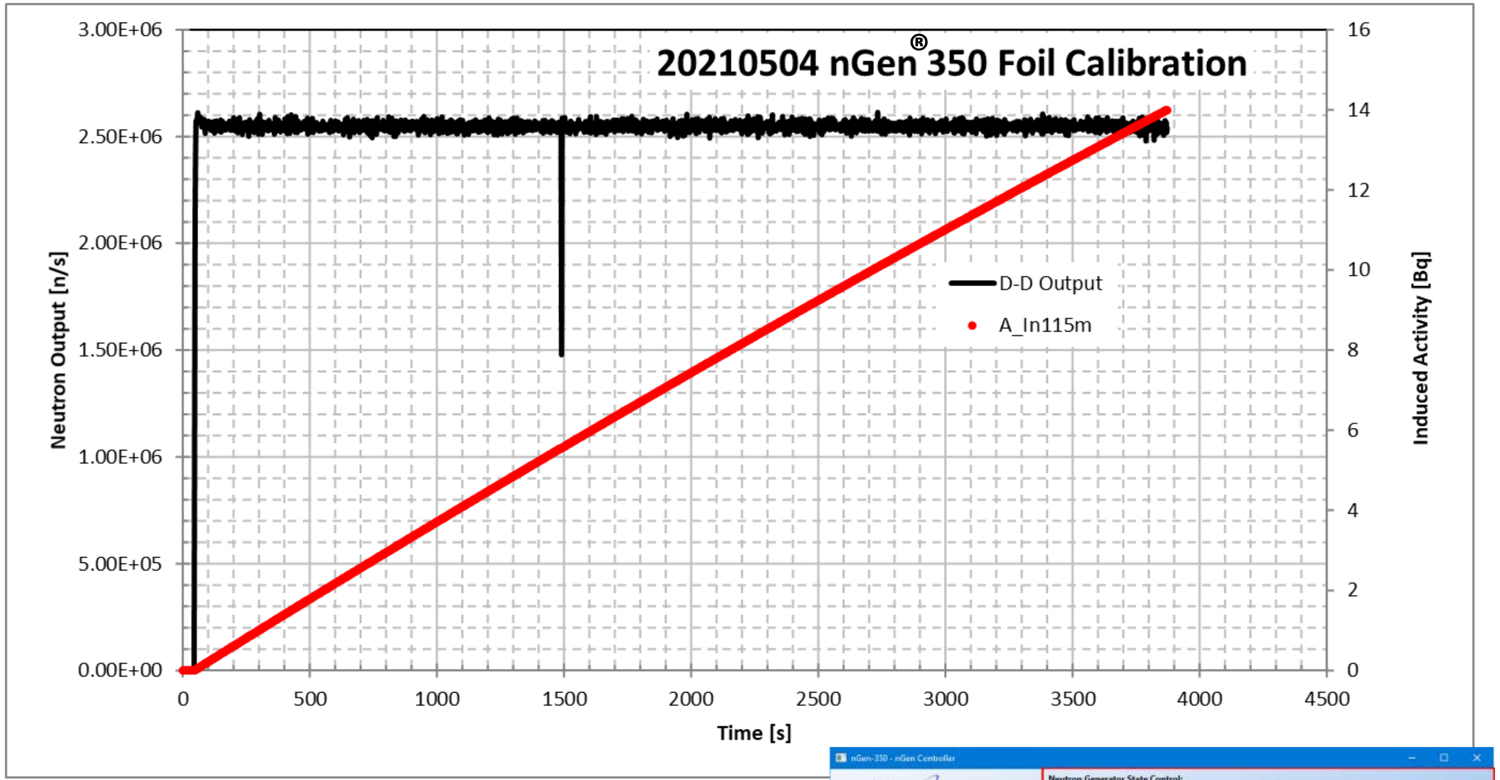
Neutron Output Over Activation Period

Activity / flux measurement details

- Measured activity: 14 Bq
- In-115m has a 4.486-hour half-life
- 18% detection efficiency (prior calibration)
- 0.34 b cross section

Flux-to-output assumptions

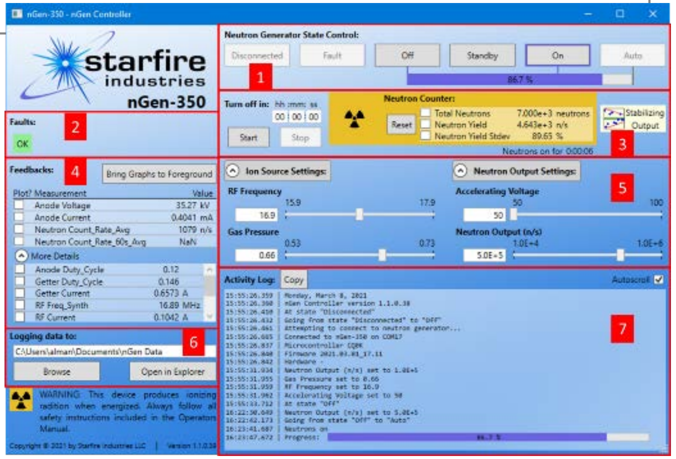
- Bare, isotropic, point source
- 11% of solid angle covered by foil
- In circle centered on end-snout target



Neutron output reported from activity is 2.55e6 DD n/s

- Agrees with REMBALL spot on
- 57° is excellent angle for REMBALL

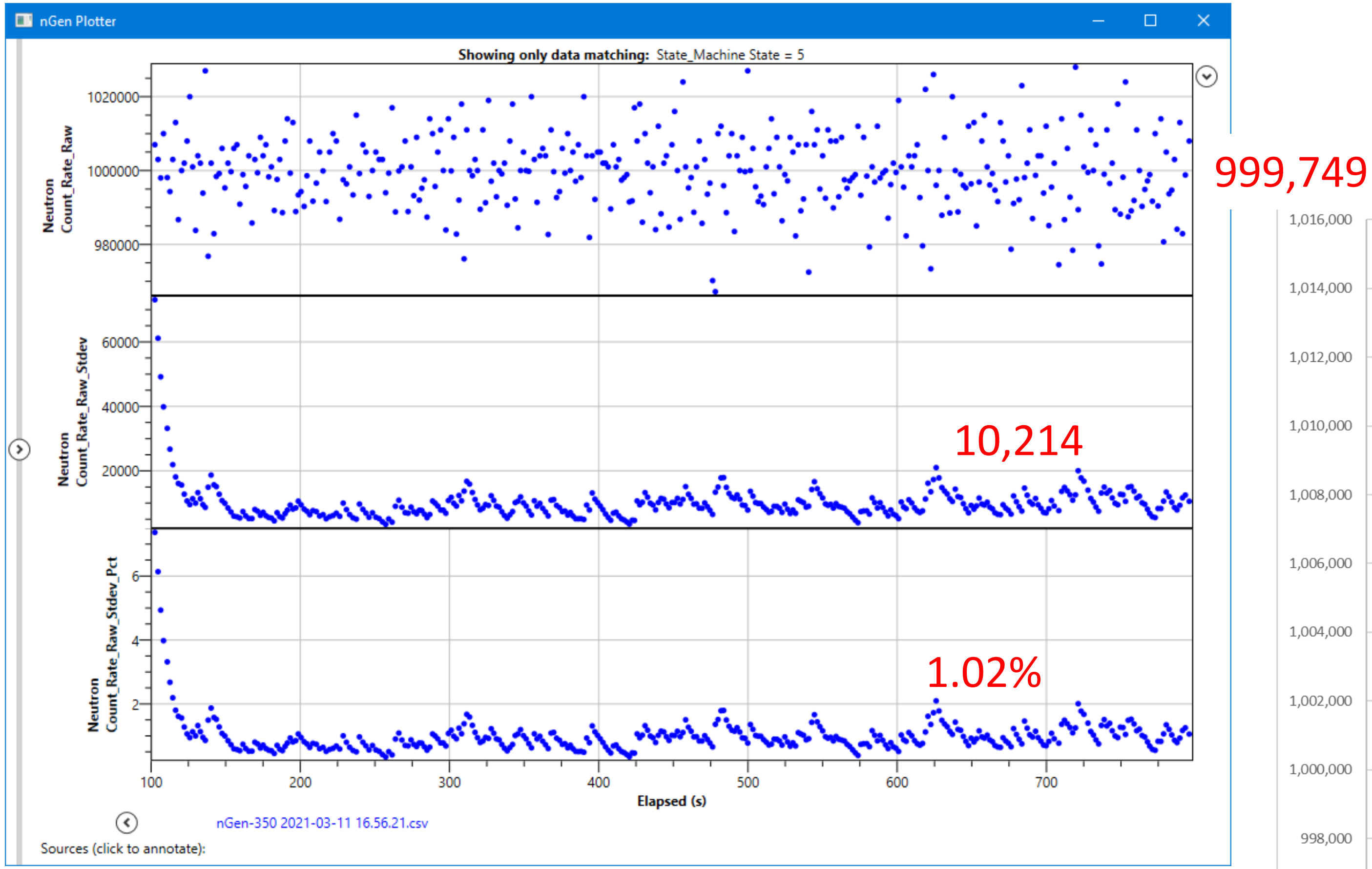
The feedback control system holds the output steady over 1-hour foil activation run

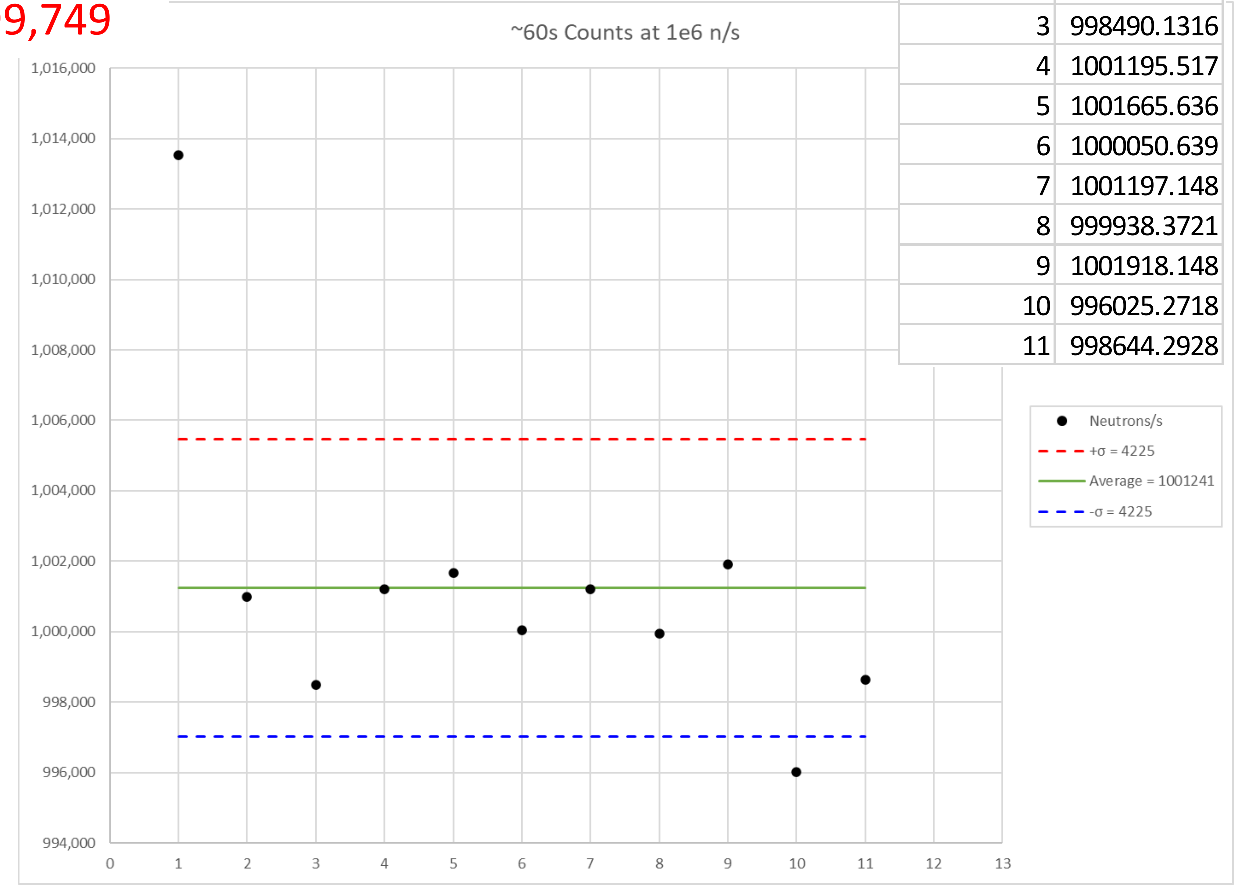


1e6 n/s Control Stability

0.42% Stdev%
Min-to-min
We have control

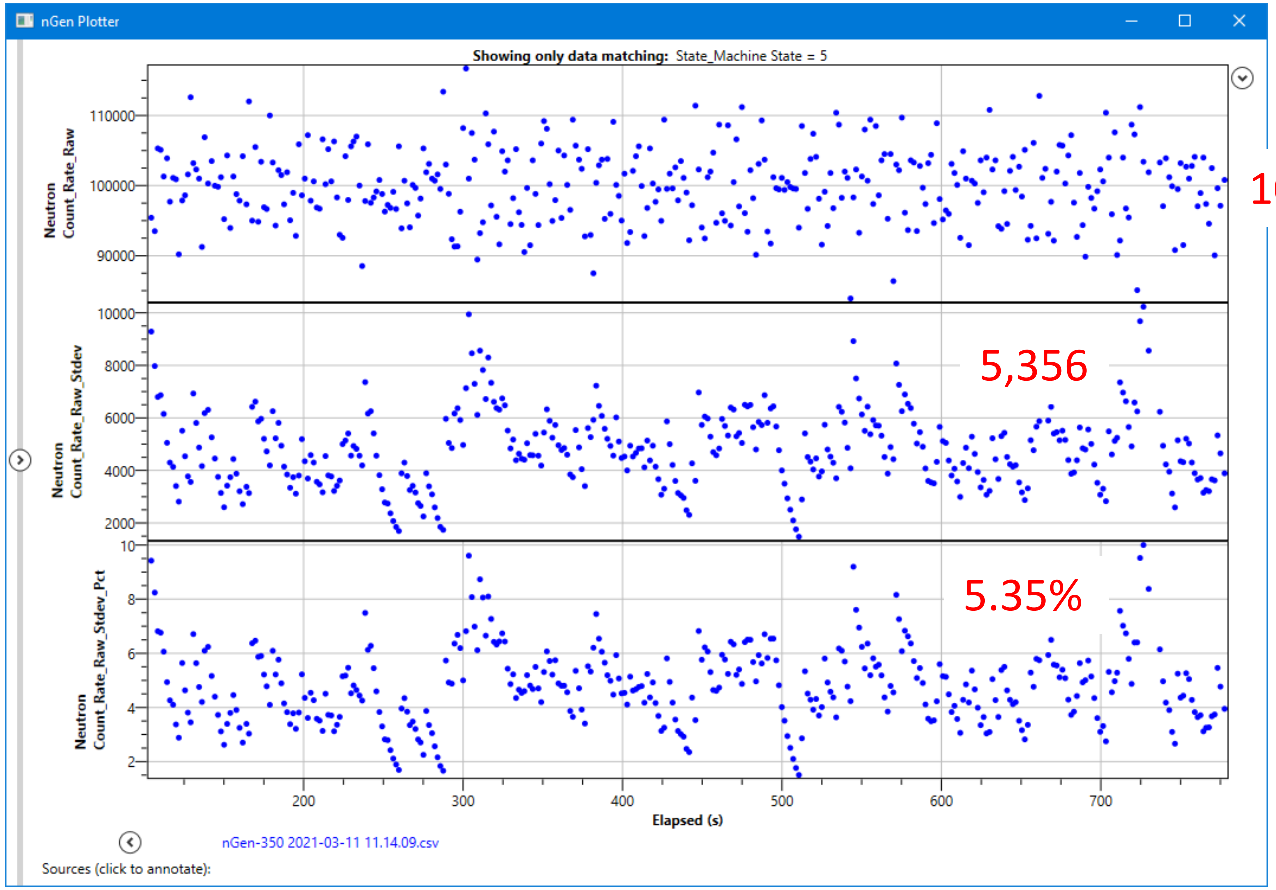
Count	11
Average	1,001,241
Stdev	4,225
Stdev %	0.42%
Minute #	Neutrons/s
1	1013531.839
2	1000990.313
3	998490.1316
4	1001195.517
5	1001665.636
6	1000050.639
7	1001197.148
8	999938.3721
9	1001918.148
10	996025.2718
11	998644.2928





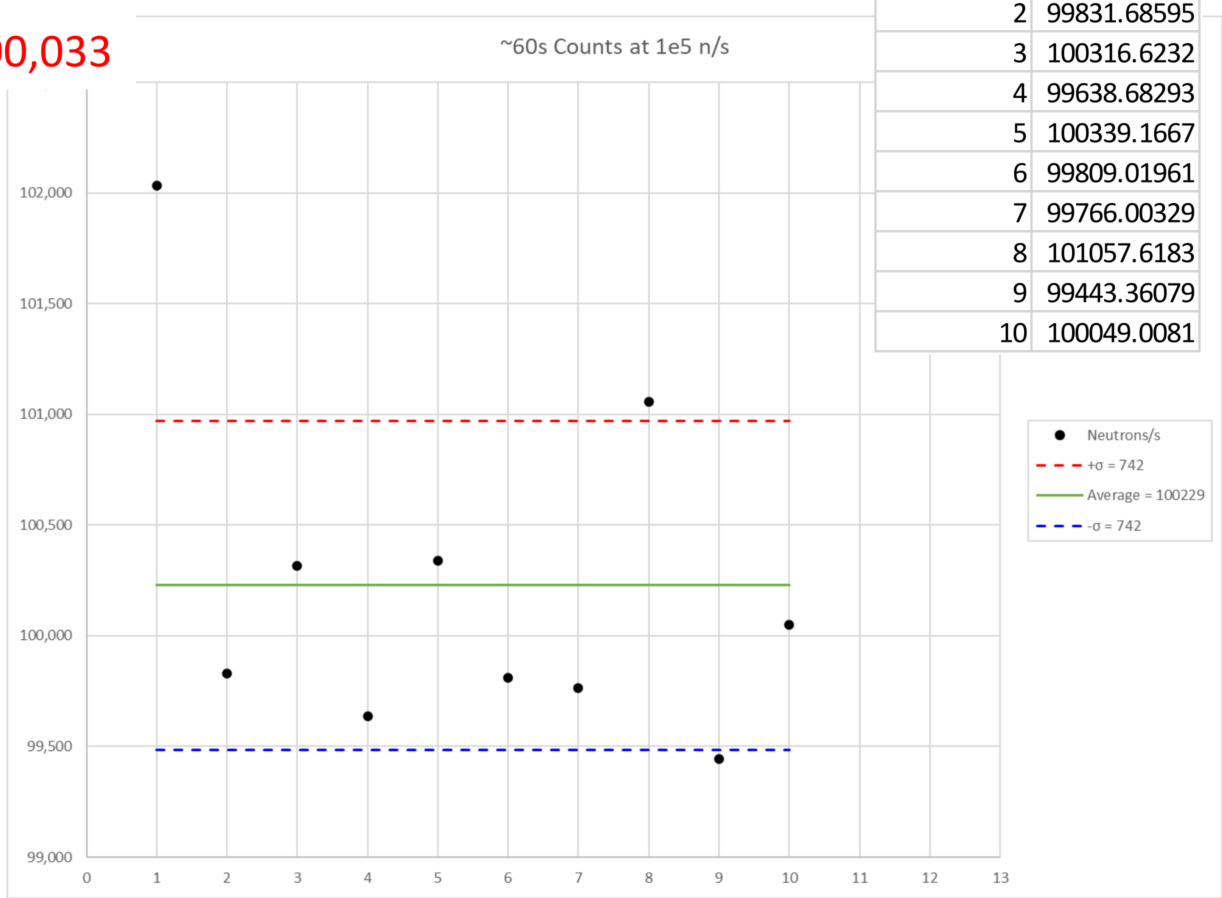
On 1-second interval, we are under 10% StdDev
Average 1.02%--greatly exceeding our goal

1e5 n/s Control Stability



0.74% Stdev%
min-to-min
We have control

Count	10
Average	100,229
Stdev	742
Stdev %	0.74%
Minute #	Neutrons/s
1	102033.8499
2	99831.68595
3	100316.6232
4	99638.68293
5	100339.1667
6	99809.01961
7	99766.00329
8	101057.6183
9	99443.36079
10	100049.0081



On 1-second interval, we are under 10% StdDev
Average 5.35%--meeting our goal

Conclusion

The end-snout configuration of the nGen® technology allows direct utilization of back-streaming D-D neutrons for real-time compensation and operational feedback

Thin-wafer RDT Domino® solid-state thermal neutron detectors can be placed on the back-side of the emission plane.

With six (6) detectors, we achieve sufficient statistics to manage 1-second count interval tracking for <10% relative standard deviation, and <1% over 1-min intervals for 1e5 DD n/s 4pi source rate.

The nGen®-350 is available up to 1e7 DD n/s in CW and DF% de-rated pulsed configurations

Applications include Am-Li replacement

Entire system ships in 1 plastic hardcase
1e6 n/s version is airline safe, checked luggage

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For more information