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NESSA: NEutron SourceS at UppSAla

A versatile neutron facility for detector physics, activation studies and SEE research

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15th Nordic Meeting in Nuclear Physics

SKC
Swedish Centre for Nuclear Technology

Swedish Energy Agency

Presentation Outline

- NESSA: Facility Overview
- Present Beamlines:
  - 14 MeV mono-energetic neutrons based on D-T reaction.
  - Tandem Accelerator based Neutron facility for selected ranges of neutron energies.
- Associated Detector Systems.
- Monte Carlo simulations.
- Current Experimental Program.
- Future Research Directions.

NESSA Team
S. Pomp (PI), G. Ericsson, M. Lantz, E. Arnqvist, L. Hägg, S. Jarl Holm., & **S. Dawn**

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The Neutron Physics Legacy at Uppsala — and the Gap NESSA Fills

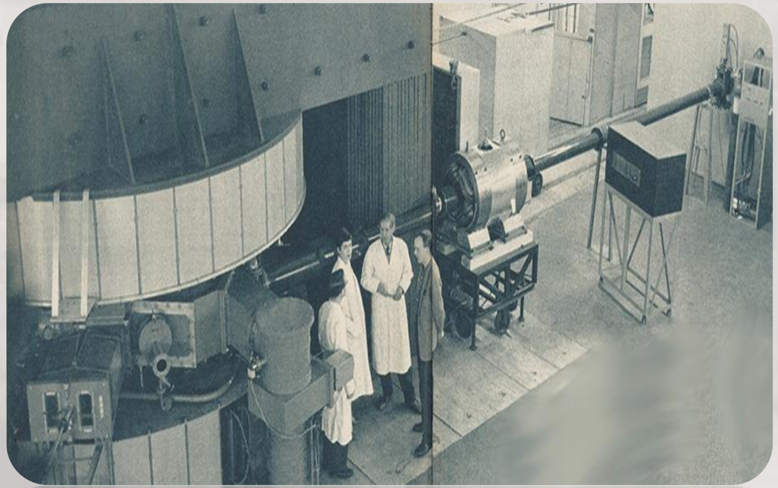
TSL : A world class high energy neutron beam for basic research: *Closure in 2013 left a major gap in Swedish neutron physics infrastructure — the gap NESSA now fills*

TANDEM Laboratory Ion beams for materials research.

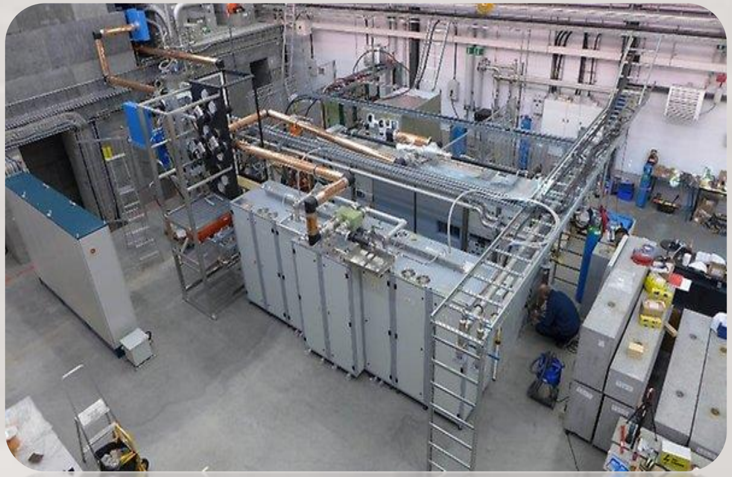
The Fast Reflectometer for Extended Interfacial Analysis **(FREIA)** for the ESS facility

TANDEM

TSL



FREIA



NESSA facility at Ångström Laboratory, Uppsala

- Initiated in 2013*.
- **Commissioned in November 2025.**
- **Sodern Genie 16™** Model.
- Door, dose and ventilation **interlocks** for Radiation Safety.
- **Flux and dose rate monitoring** from outside control station.

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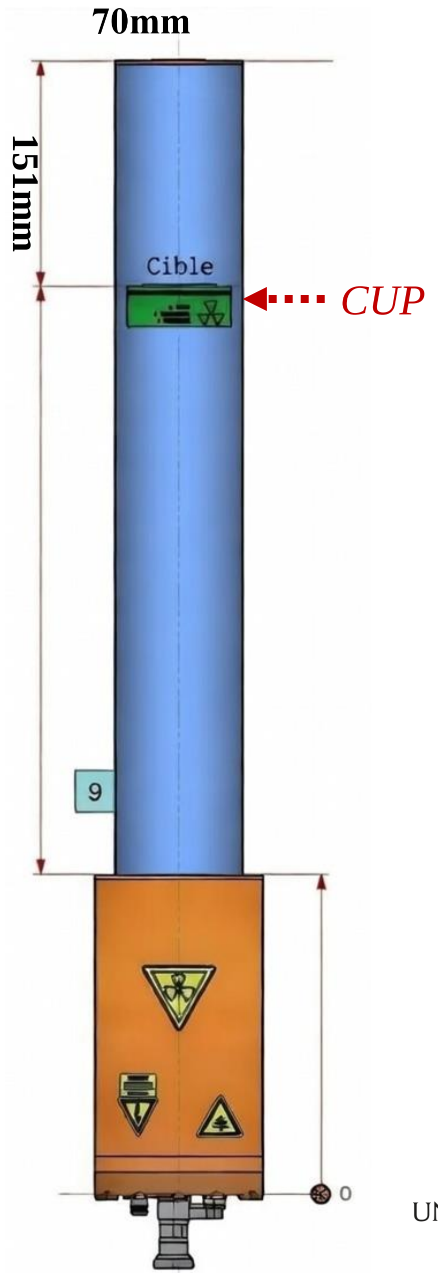
**H. Sjostrand et al.; Total Monte Carlo Evaluation for Dose Calculations, RPD, 2013*

Key Technical Specifications of the Neutron Generator

- Peak neutron yield: **4.7 × 10^8 n/s/4π sr**
- Tritium inventory (2018): **120 GBq**
- Maximum achievable thermal flux at 3.5 cm from target (Closest User Position: CUP)
- Operating modes: continuous (DC) and **pulsed**
- Pulsed mode (current-limited): minimum achievable pulse: **10 µs**
- Pulse timing controlled via proximity box; **external trigger compatible**



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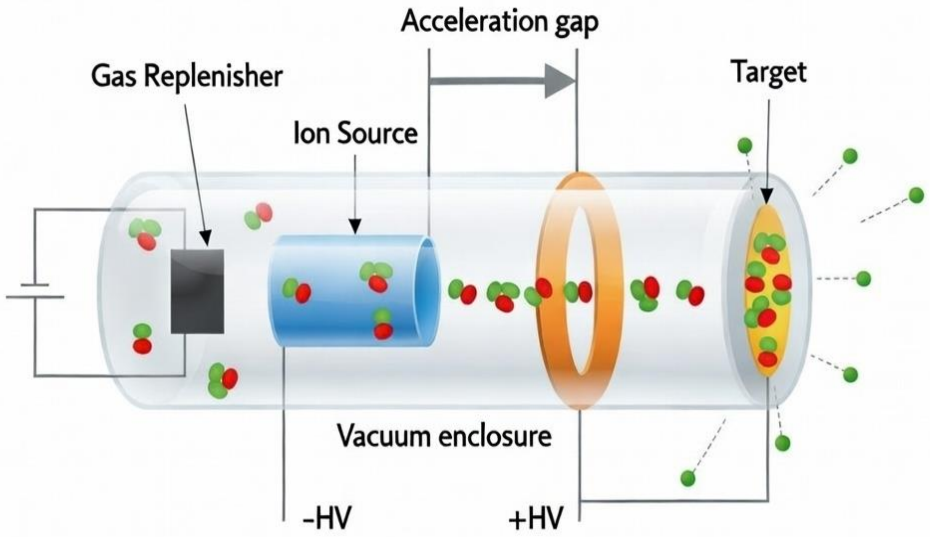
Principal Components of the D-T Neutron Generator



● ***proton***
● ***neutron***

- **Gas replenisher**: regulated D-T fuel supply.
- **RF ion source**: generates D-T plasma.
- **HV accelerating stage**: 40–120 kV.
- **Tritiated target (Ti-T):** emits 14.1 MeV neutrons.
- Both source and target use an equimolar D:T mixture (50:50).

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Neutron Flux: Measurement Parameters and Notation

$$Y = k \cdot R_{\text{Rep}} \cdot V_{\text{HV}}^{3.5} \cdot \text{Current}$$

Parameter Definitions:

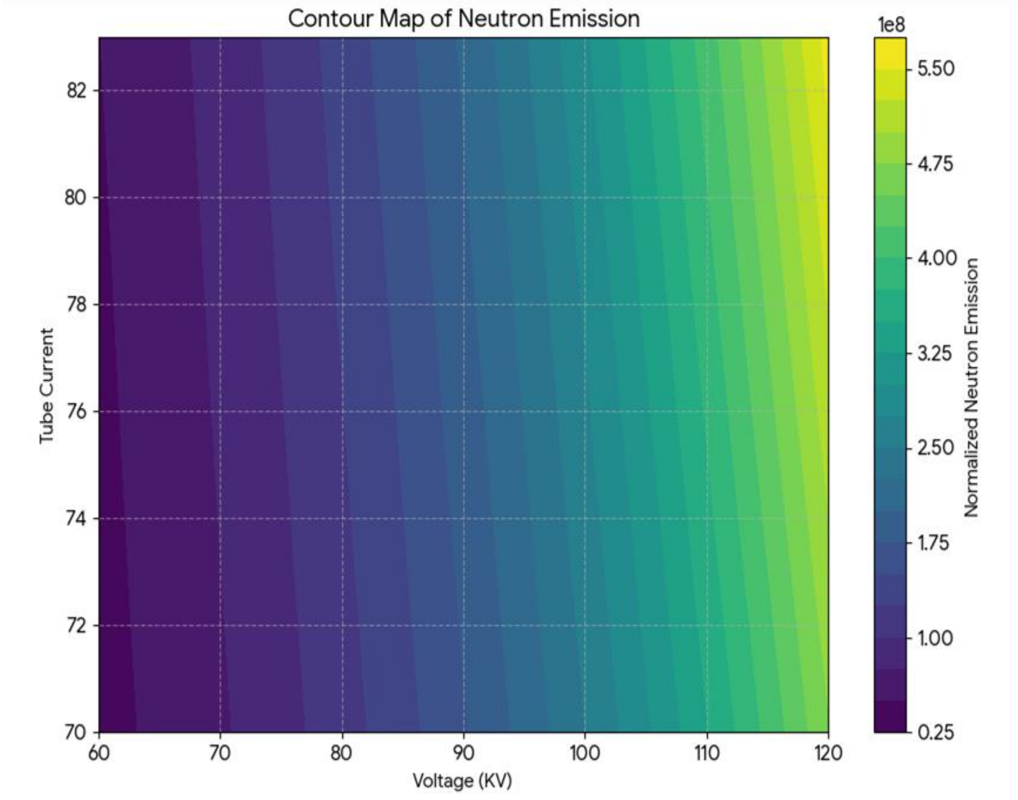
R_{Rep} — Gas replenisher resistance (mΩ). controlling gas pressure and D-T fuel flow.

V_{HV} — Applied high voltage (kV). governs ion beam energy and thus neutron yield.

I_{tube} — Tube current (µA). directly proportional to the neutron production rate.

At 120 KV- V_{HV}, 80 µA- I_{tube} & 1670 mΩ- R_{rep}

Y=4.4 x 10^8 n/s.



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Associated Detector Systems and Instrumentation

- Micro-fission chamber (μFC) for real-time beam flux monitoring — both ^{235}U and ^{238}U variants available.
- NaI(Tl) & $LaBr_3$ scintillators for prompt gamma-ray spectroscopy.
- EJ-301 liquid scintillator for fast-neutron detection and n/γ discrimination.

- High Efficiency HPGe system for gamma spectrometry.
- WENDI extended energy neutron dose-rate meter

Fission Chambers and Liquid scintillators placed in closed user position

Building up the lead castle for HPGe in NESSA

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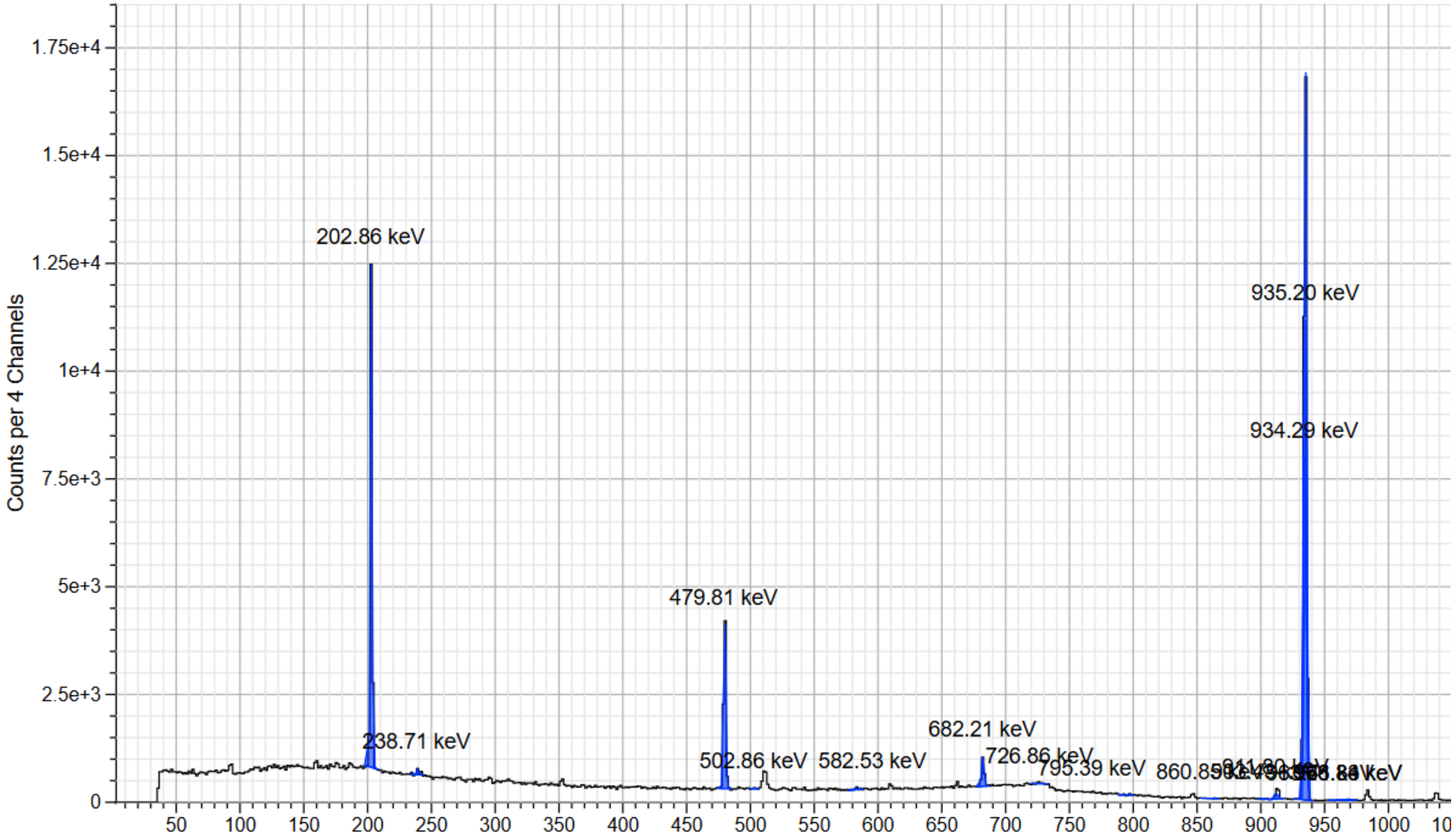
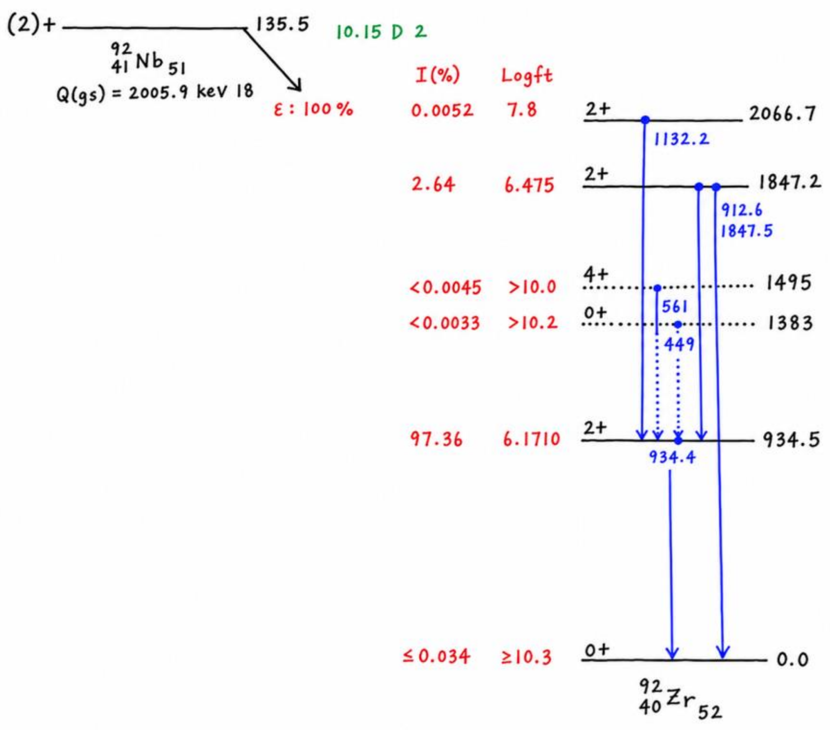
^{93}Nb Activation Foil Dosimetry and Flux Monitoring





- **^{93}Nb** is one of the most suitable elements for absolute yield measurements via neutron activation.
- **^{93}Nb(n,2n)^{92m}Nb → 934.44 keV** γ with 99.15 % branching ratios.
- σ **~ 0.457 barn at 14 MeV**.
- **100% isotopic** abundance

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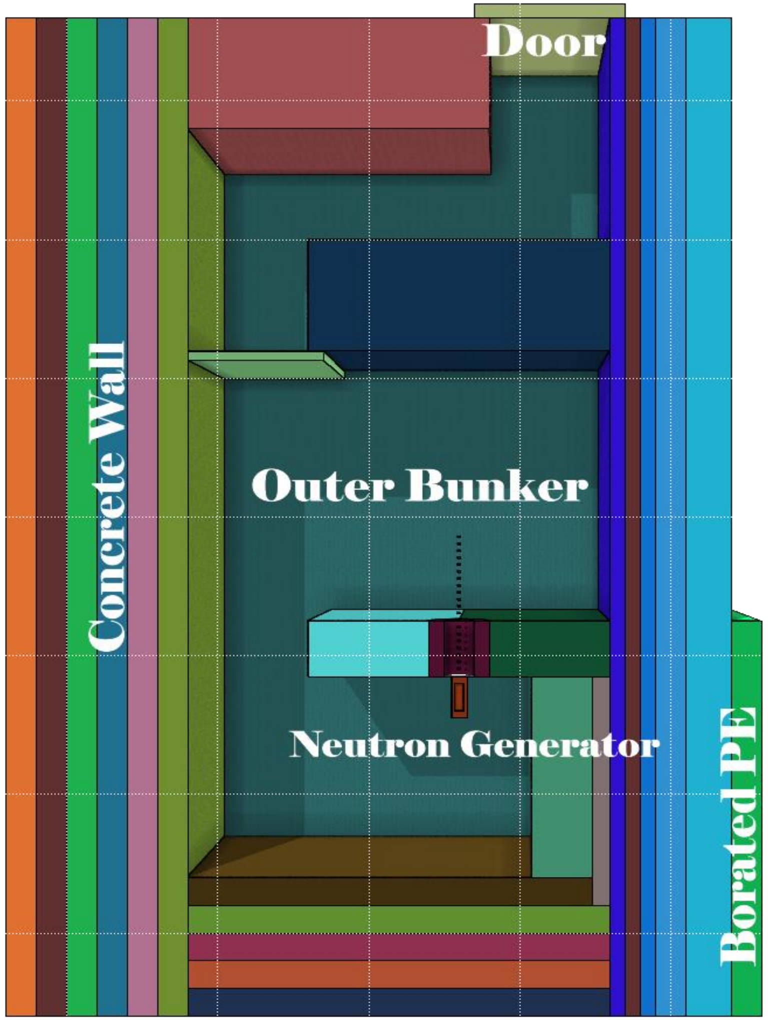
Absolute Neutron Yield from $^{93}Nb(n,2n)^{92m}Nb$ Activation Foil

$$Y = (4.33 \pm 0.36) \times 10^8 \text{ n/s}$$

D. NEUTRON YIELD CALCULATION		
Measured flux Φ at foil (n/cm²/s)	1,510E+06	n/cm²/s
Flux uncertainty δΦ (n/cm²/s)	1,001E+05	n/cm²/s
r² (cm²)	22,563	cm²
Yield Y_point (n/s) — point source	**4,282E+08**	n/s
Yield Y_geom (n/s) — geom corrected	4,330E+08	n/s
Yield Y_final (n/s) — full correction	**4,325E+08**	n/s
E. UNCERTAINTY ON NEUTRON YIELD		
δY/Y from flux δΦ/Φ	6,630%	fraction
δY/Y from distance δr/r (×2)	1,000%	fraction
δY/Y from anisotropy δA/A	5,000%	fraction
δY/Y from C_geom	0,300%	fraction
Combined δY/Y	**8,370%**	fraction
Absolute uncertainty δY (n/s)	**3,620E+07**	n/s

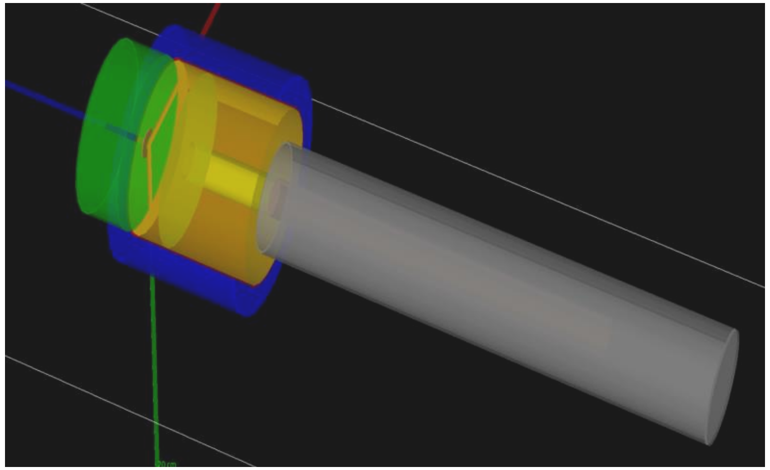
- Calibrated values during commissioning is 4.4 x 10^8 n/s.
- Source degrades over time (6 years old)
- Uncertainty from HPGe counting is only statistical uncertainty.

Monte Carlo Modelling of the complete beamline



3D reconstruction of NESSA facility

- Major Monte Carlo codes have been used to reconstruct complete NESSA geometry and detector responses.
- ***Geant4. FLUKA. MCNP. PHITS & SERPENT.***
- Activation analysis of different structural materials, air activation.
- Neutron Spectrometry and dosimetry at different irradiation positions.
- Intercomparison of different physics models, cross-section libraries and Monte Carlo codes.



Reconstruction of HPGe detector

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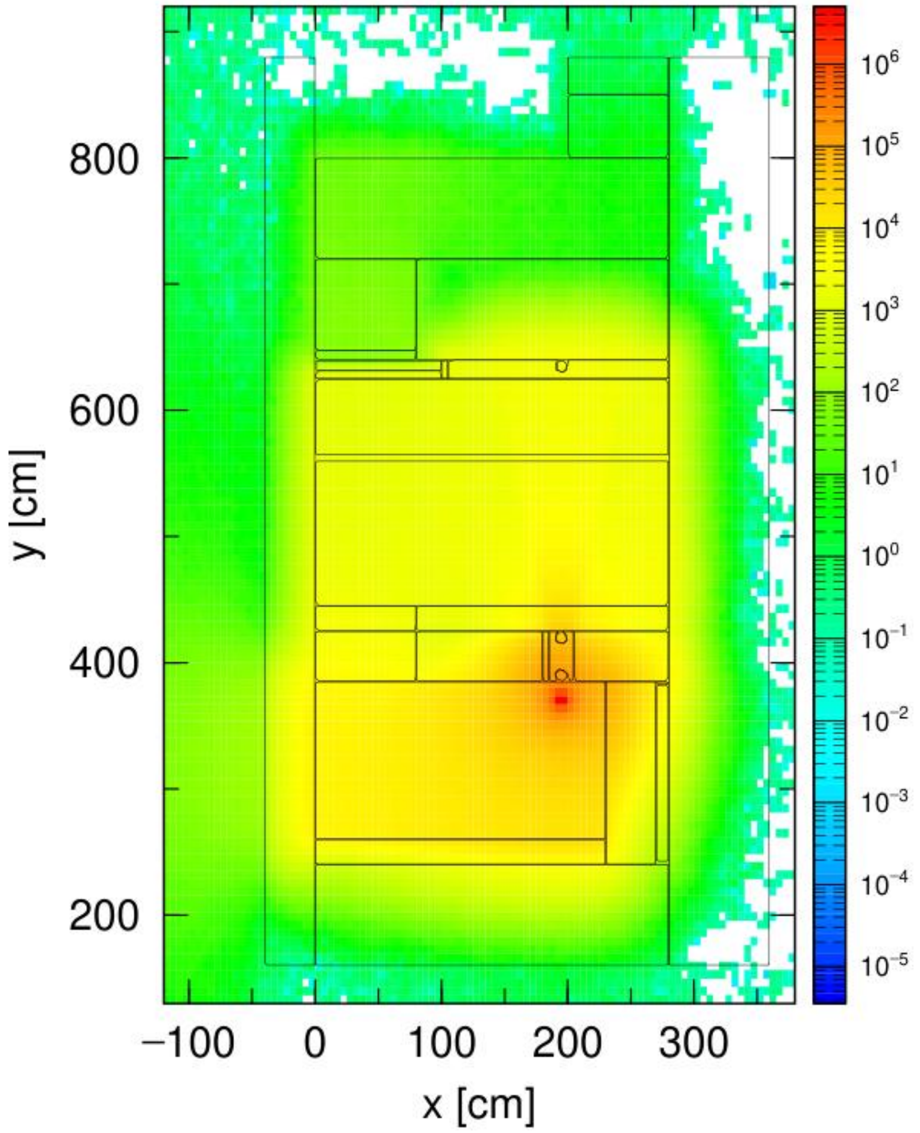
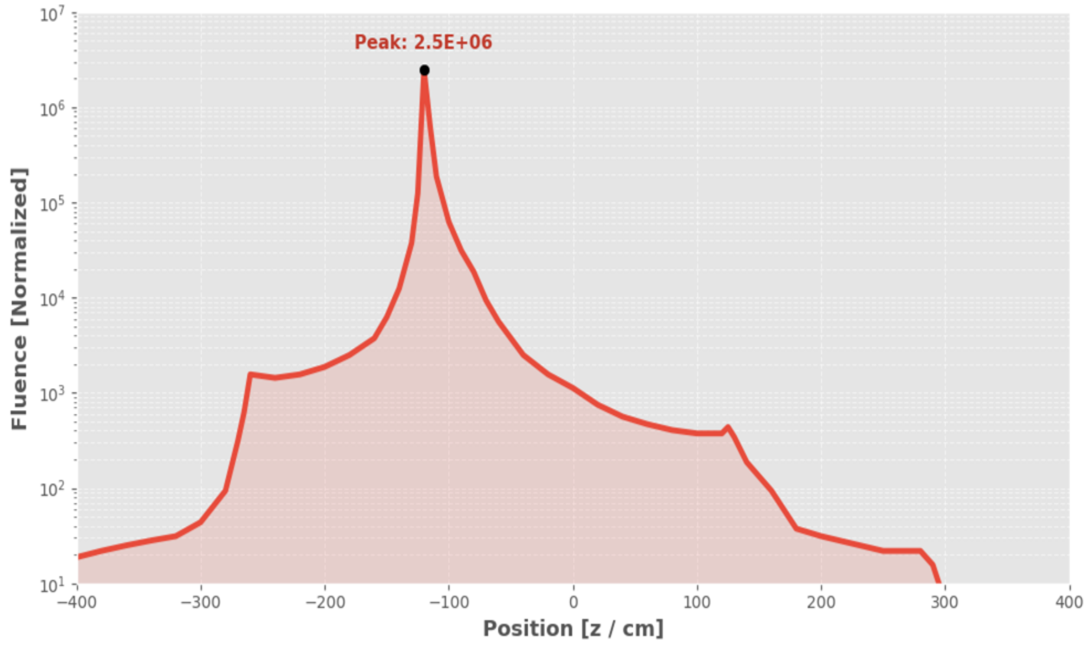
Simulated Neutron Fluence



Neutron Fluence Map in NESSA bunker using PHITS



- Characterization of Neutron fluence and spectra through out the beam hall.
- Maximum flux at CUP is **2.46 x 10^6 n/cm^2/sec.**
- Important for detector characterization. activation analysis and safety report.

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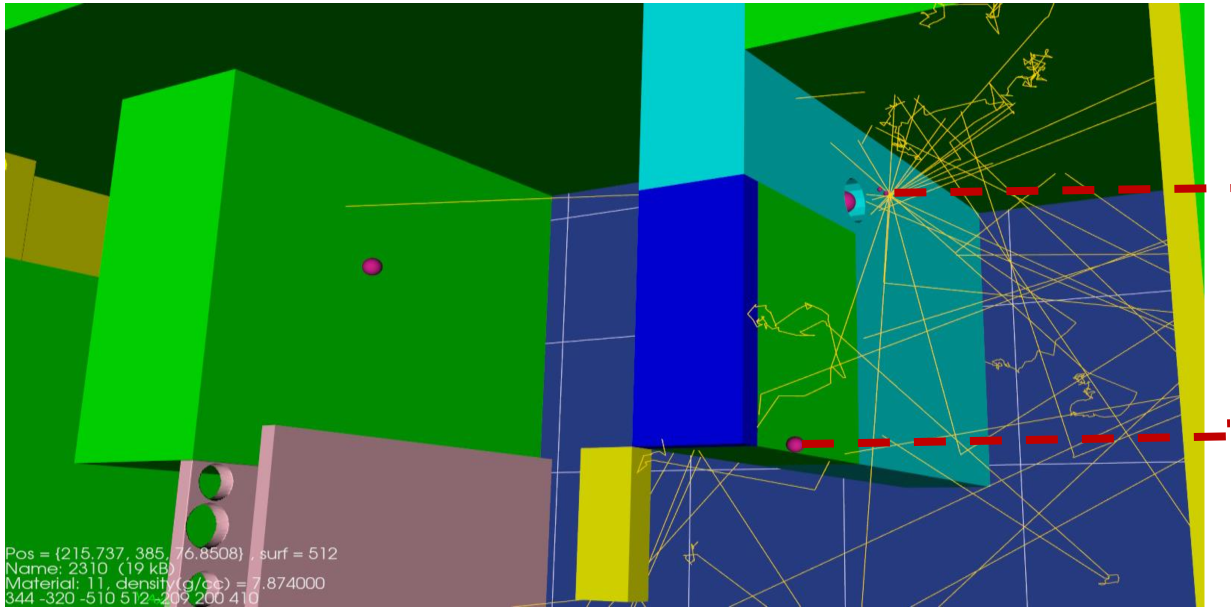
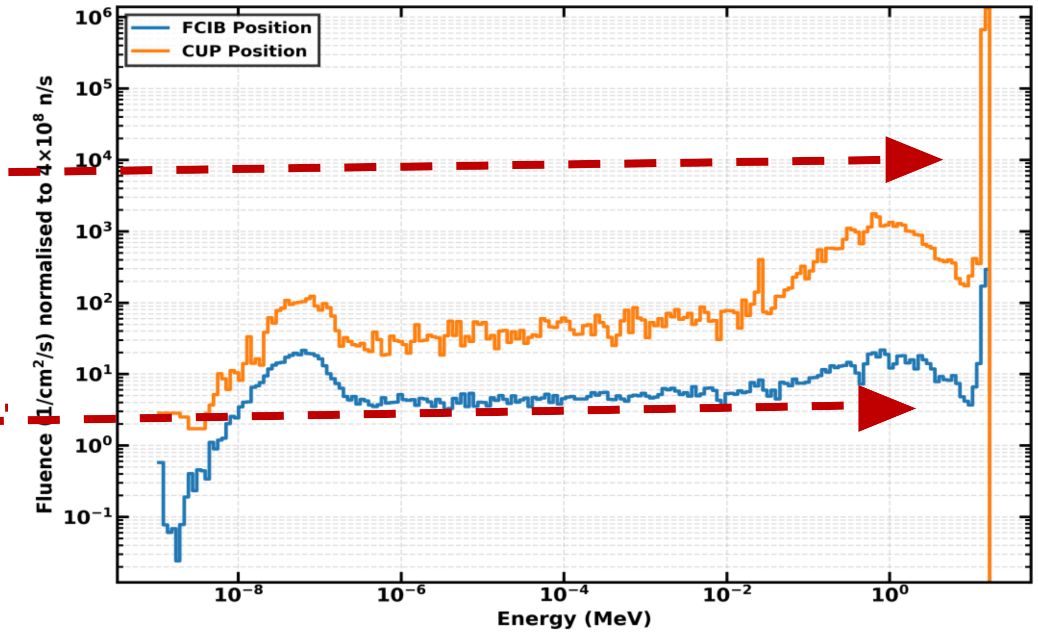
Characterization of Neutron Spectra





Location / Energy Range	Fluence (1/cm²)	%	Notes
CUP Location			
Thermal (<10 eV)	2.76E+03	0.14	Room-return thermal
10 eV - 100 keV	5.78E+03	0.28	Epithermal region
Fast (≥100 keV)	2.03E+06	99.58	Primary D-T (~14.1 MeV)
FCIB Location			
Thermal (<10 eV)	2.14E+03	**25.06**	Room-return thermal
10 eV - 100 keV	1.91E+03	22.40	Epithermal region
Fast (≥100 keV)	4.49E+03	**52.53**	Primary D-T (~14.1 MeV)

- **Room back-scattering components** are significant due to relatively compact geometry.
- At certain irradiation positions. it can be up to 50%.
- Important for detector calibration and response studies.

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Fission Chamber response in NESSA

uFC location experiment	coating	σ_{avg}(b)	Measured count rate (cps) (*)	Calculated rate (MCNP) (ε = 65%)	Calculated rate (PHITS) (ε = 65%)
CUP*	^{235}U	**2.45**	**34.16**	**36.1 (+5.7%)**	**33.10 (-3.1%)**
CUP*	^{238}U	**1.15**	**10.20**	**15.6 (+53%)**	**14.4 (+41%)**
FCIB **	^{235}U	**92.00**	**2.213**	**2.224 (+0.5%)**	**2.060 (-6.9%)**
FCIB**	^{238}U	**0.36**	**11.01x10^{-3}**	**8.60·10^{-3} (-22%)**	**7.69·10^{-3} (-30%)**

R_{235}/R_{238} is the spectral index

Fission chamber in irradiation positions

* CUP is about 4 cm from the neutron emitting target
** FCIB is about 130 cm from the neutron emitting target

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Ericsson. G.. Pomp. S.. Hägg. L.. & Dawn. S. (2026). Development of a Neutron Field Monitoring System for the DT Neutron Generator Facility NESSA

Gamma Ray in the neutron field: Simulation Results

Type	Nuclide	Reaction	γ Energy (MeV)	T½	Source in NESSA
PROMPT	^{1}H	^{1}H(n.γ)^{2}H	**2.223**	—	PE shielding. thermalised n
PROMPT	^{12}C	^{12}C(n.n'γ)	**4.439**	—	Borated PE. organic material
PROMPT	^{16}O	^{16}O(n.n'γ)	**6.129 / 6.917**	—	Concrete walls. air in hall
PROMPT	^{56}Fe	^{56}Fe(n.n'γ)	**0.847 / 1.238**	—	Iron plug. collimator wall
DELAYED	^{16}N	^{16}O(n.p)^{16}N	**6.129 / 7.115**	7.1 s	Concrete & air; dominates post-beam dose
DELAYED	^{24}Na	^{27}Al(n.α)^{24}Na	**1.369 / 2.754**	14.96 h	Al in structural material

□ **Prompt (during beam-on)** □ **Delayed (post beam-off. activation)**

SHORT-LIVED minutes — hours

Isotope	T½	Reaction	γ (keV)
V-52	3.74 min	*V-51(n,γ)*	**1434.1 keV**
Al-28	2.24 min	*Al-27(n,γ)*	**1778.9 keV**
Mg-27	9.46 min	*Al-27(n,p)*	**843.8 keV**
C-11	20.4 min	*C-12(n,2n)*	**511.0 keV**
Mn-56	2.58 h	*Fe-56(n,p)*	**846.8 keV**

- Production of Prompt and Delayed gamma due to neutron activation.
- Plays important role in radiation protection.
- An important resource for activation studies, beam characteristics, gamma detector response.

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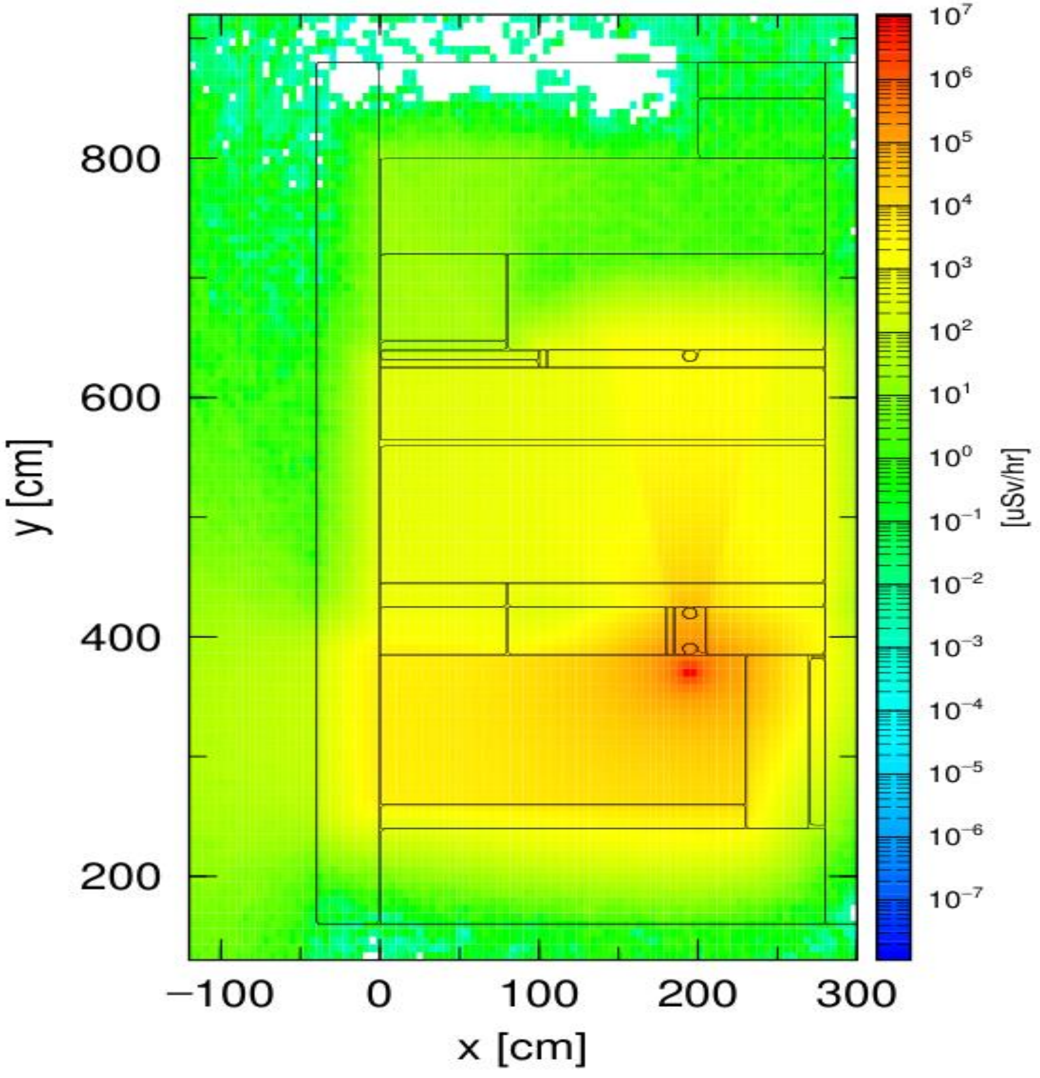
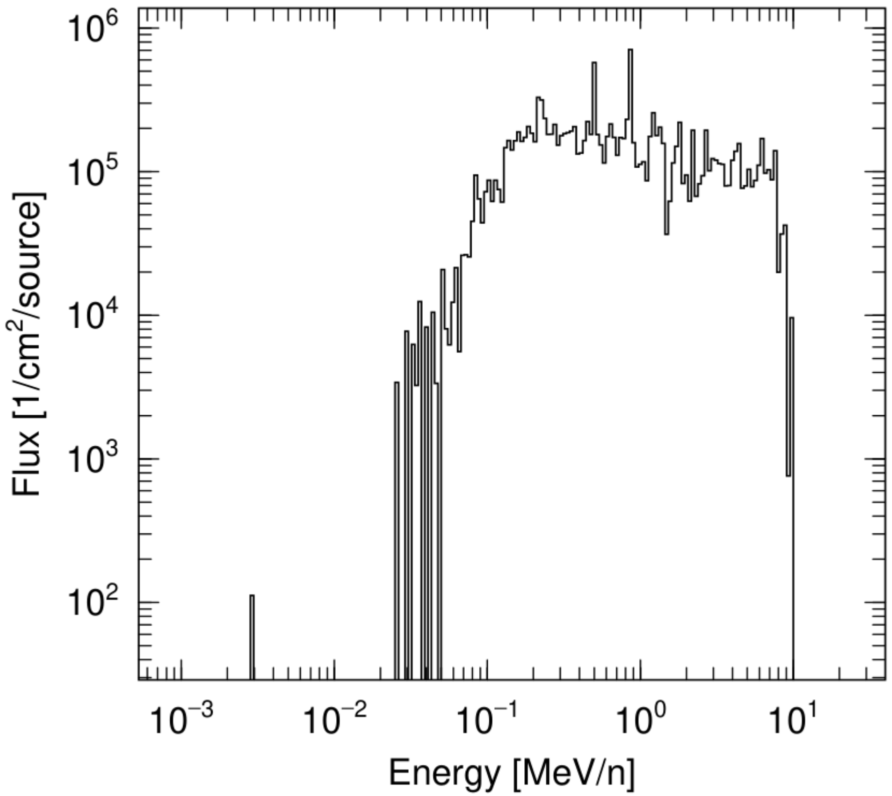
Gamma Ray in the neutron field



Distribution of gamma dose rate in source plane using PHITS

- Dose rate near the closest user position can reach 10 Sv/h.
- Wide distribution of energies. Can reach up to 10 MeV.
- Dose rate out side bunker is < 1µSv/h



Simulated Prompt γ spectra at CUP using PHITS

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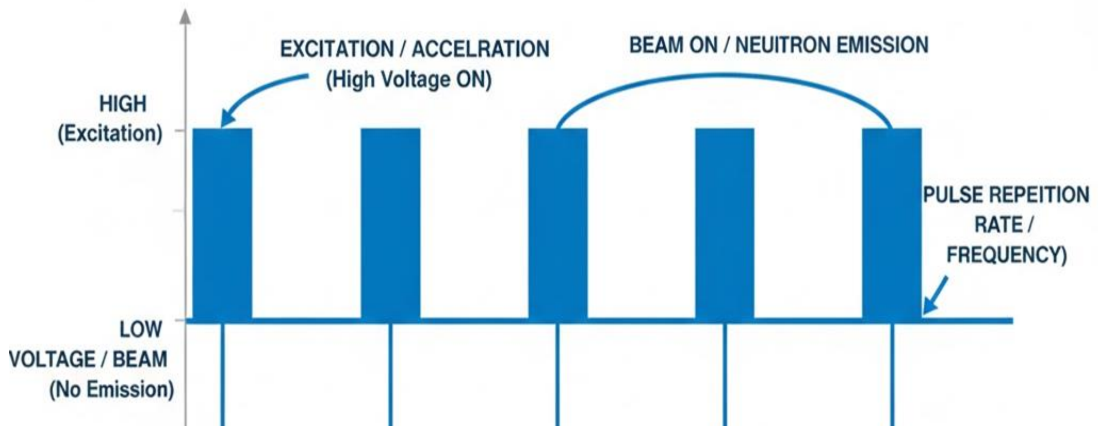
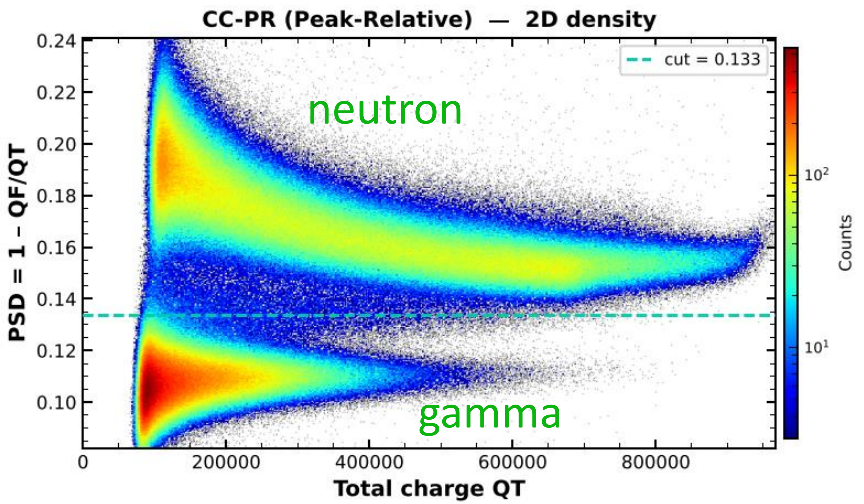
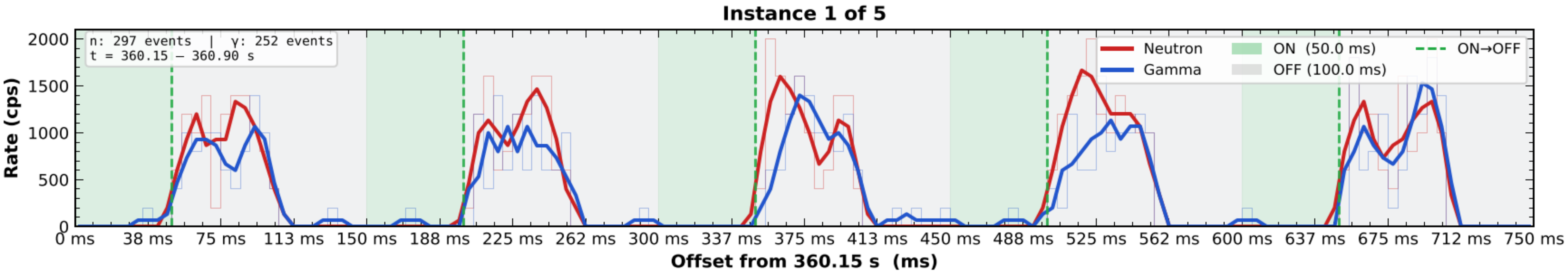
Liquid Scintillator in Pulse Mode : Die-Away Phase



Neutron Generator in Pulse Mode



n/γ discrimination



- *Important application in studying **Die-Away** phase in nuclear disarmament*

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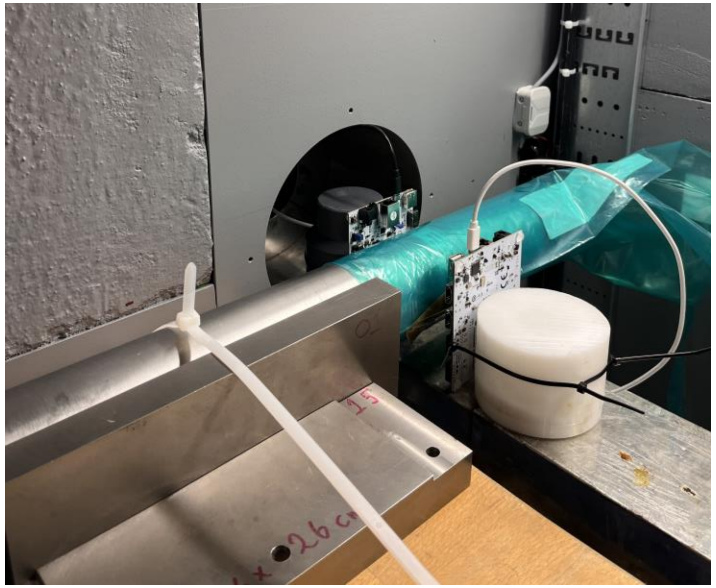
Studying SEE and Electronics Damage at NESSA

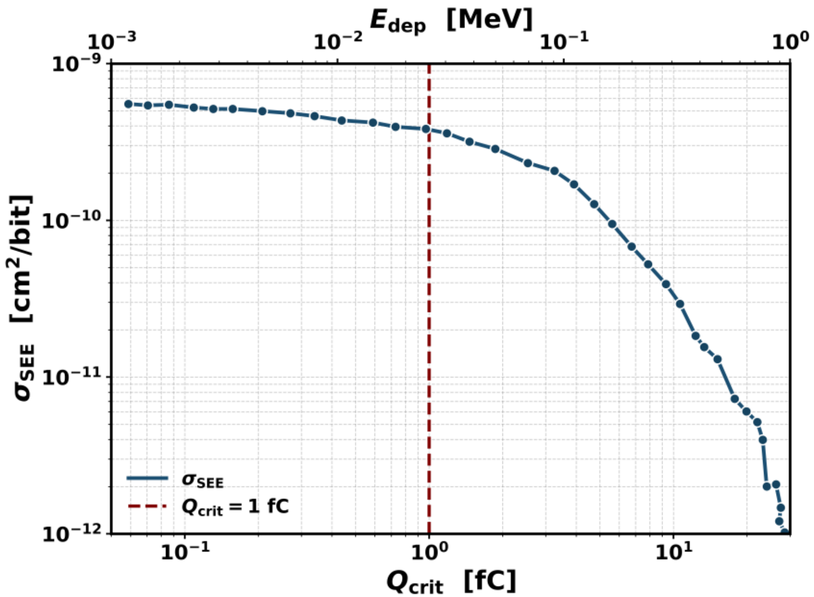


Irradiation of electronic chips at NESSA

- Major Goal of NESSA: studying electronics damage like Single Event Error/Upset(SEE).
- Direct implication in Space Science. Reactor Electronics. Aviation Safety.

- Irradiated two chip configurations (Linear Feedback Shift Register and Fast Fourier Transform)
- Observed single bit-flip errors in program memory requiring automatic reconfiguration.
- Error rates scaled dramatically with resource utilization: FFT (86% chip utilization) suffered ~10 x more errors in comparison to LFSR design.

- Error cross-section has been studied with G4SEE Monte Carlo simulation code.



Evaluation of SEE cross-sections as a factor of critical charge using G4SEE simulation

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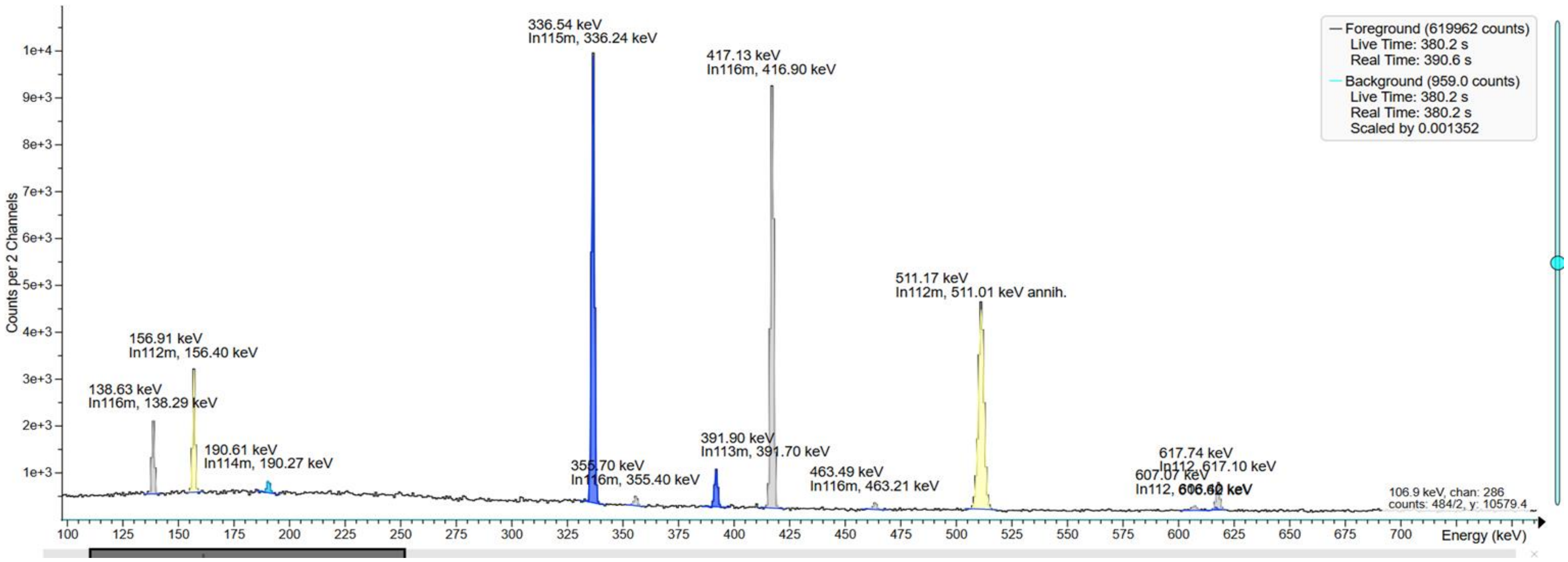
$^{115/113}$In +14 MeV neutron: Initial Results



^{115}In reactions (95.7% abundant):

- **(n,2n)^{114m}In** — threshold 10.4 MeV, 49.51 d, 190.27 keV —absolute yield calibration reaction: 1210 ± 71 mb
- **(n,γ)^{116m}In** — thermal capture, 54.29 min, 1097/1293 keV — the room-return thermal contribution: Simulation benchmark
- **(n,n')^{115m}In** — threshold 0.34 MeV, **4.486 h**, 336 keV — inelastic threshold detector : T½ = 4.353 ± 0.224 h.

^{113}In reactions (4.3% abundant):

- **(n,2n)^{112}In** — threshold 9.2 MeV, dual isomers at 156.5 617.5 keV — IYR measurement

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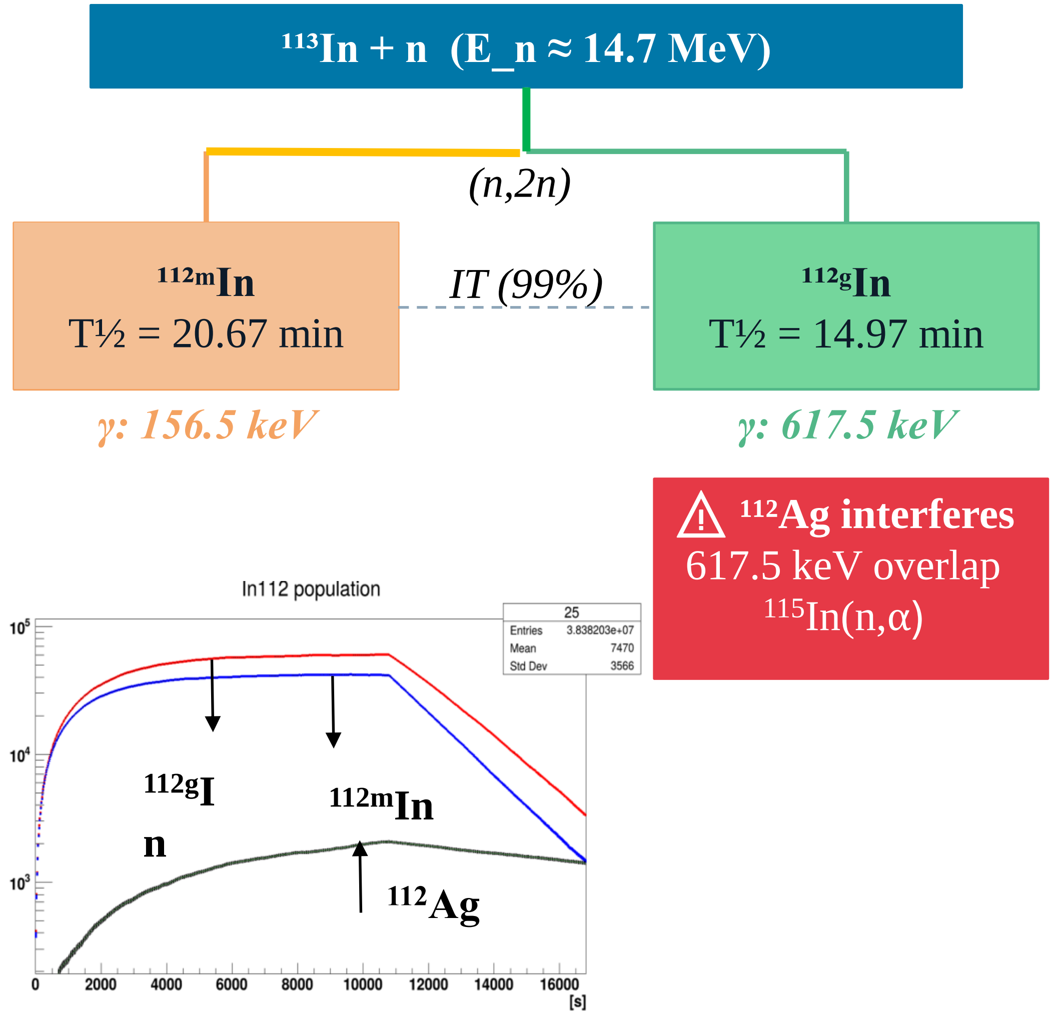
^{113}In(n,2n) Isomeric Yield Ratio — Decay Scheme & Measurement

Decay Scheme



Measurement & Analysis Chain

1. Foil in 14.7 MeV neutron beam
   Y ≈ 4.3×10^{8} n/s (^{93}Nb calibration)
2. 156.5 keV (^{112m}In) + 617.5 keV (^{112g}In + ^{112}Ag)
   Timed series: cool, count, repeat
3. Source-term equations for all phases:
   irrad. → cooling → counting; Ag-112 deconvolution
4. Full geometry simulation of HPGe + foil;
   efficiency, self-absorption, angular distribution
5. $R = A_{156} / A_{617}$_corrected
   Statistical + systematic uncertainties

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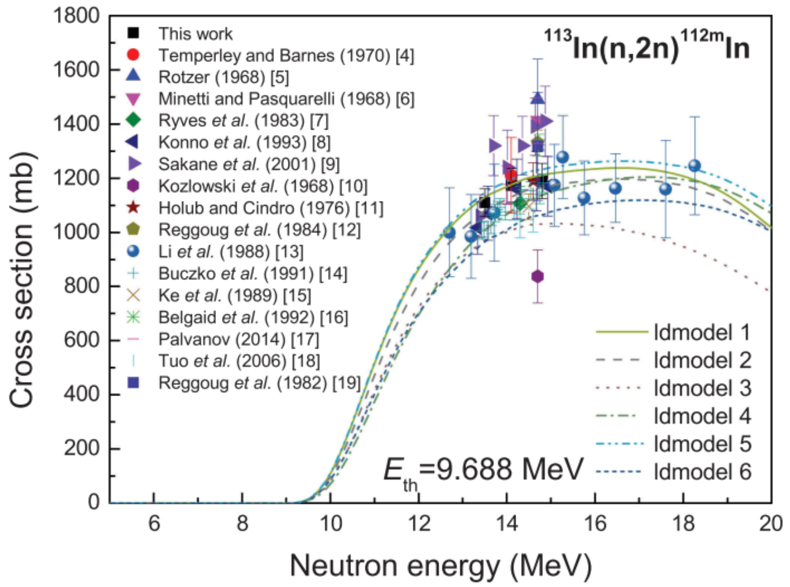
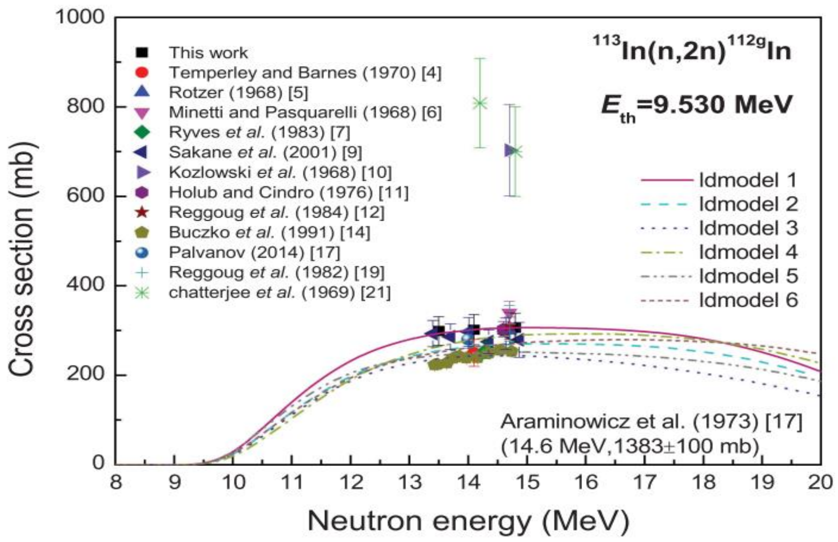
^{113}In(n,2n) IYR — Results at 14.7 MeV & Cross-Checks

Measured IYR (Y^m / Y^g): 3.82 ± 0.47
*****first measurement at NESSA***

Geant4 Validation

- HPGe detector geometry fully modelled.
- Foil self-attenuation at 156 & 617 keV.
- Simulated peak efficiencies agree with IAEA source calib.
- G4Radioactivation used for cascade verification.
- Intercomparison of HP, INCLXX, **QGSP_BIC**, FTFP_BERT physics model.





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Luo et al., 2017, Nuclear Science and engineering, Volume 188

5 MV 15SDH-2 Pelletron facility for Neutron production

Target	Primary (p.n) reaction	Q (MeV)	Eth (MeV)
Be	$^{9}Be(p.n)^{9}B$	−1.85	2.06
LiF	$^{7}Li(p.n)^{7}Be$	−1.64	1.88
V	$^{51}V(p.n)^{51}Cr$	−1.53	1.56
Mn	$^{55}Mn(p.n)^{55}Fe$	−1.02	1.04
Mo	$^{98}Mo(p.n)^{98}Tc$	−2.47	2.50
Zn	$^{68}Zn(p.n)^{68}Ga$	−3.72	3.78
Fe	$^{56}Fe(p.n)^{56}Co$	−5.35	5.44
B	$^{11}B(p.n)^{11}C$	−2.76	3.02
C	$^{13}C(p.n)^{13}N$	−3.00	3.24

- Complementary Neutron Beam facility at Tandem Laboratory at Uppsala University.
- Proton beam up to 10 MeV energies can be achieved.
- Several targets have been tested for neutron production

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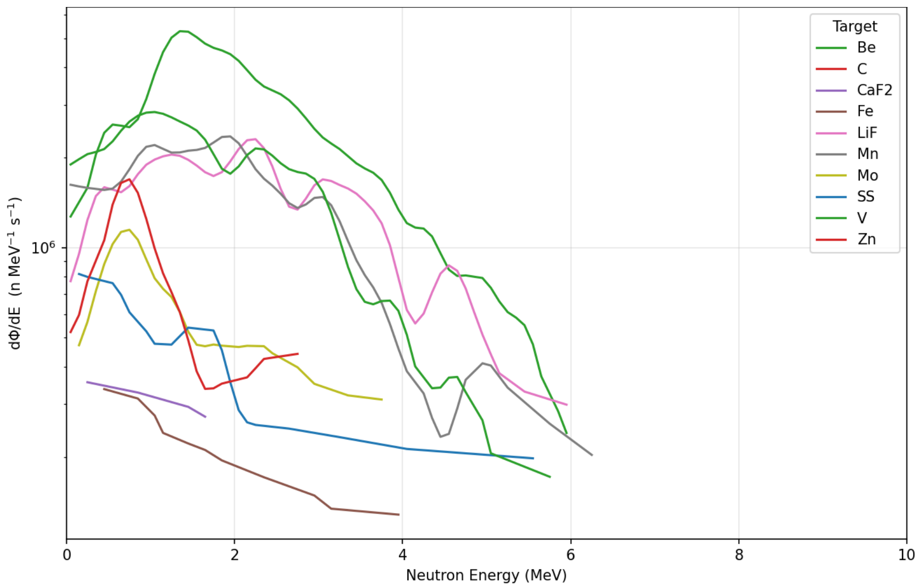
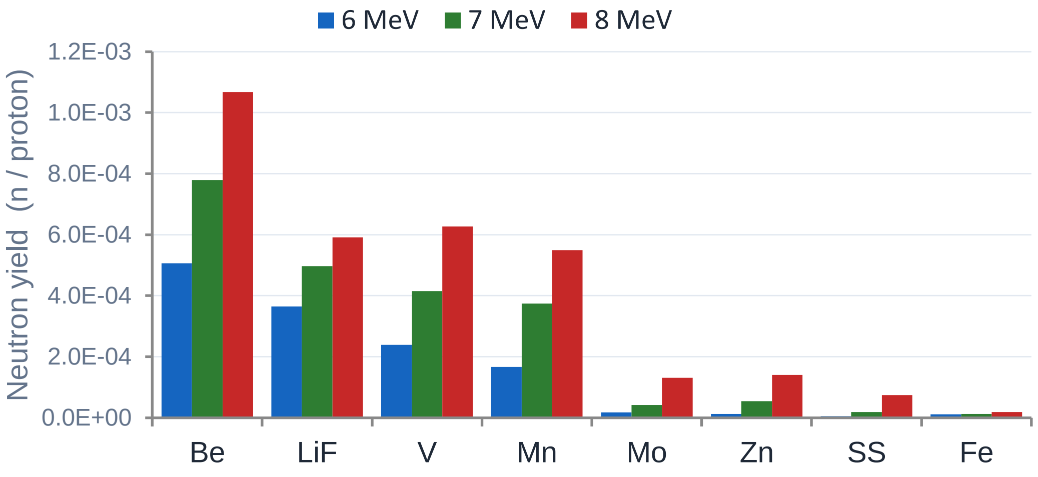
8MeV proton on different targets

Target	Measurement (n/s/nAmp)	Simulation (n/s/nAmp)
Be	**1.03 x 10^{07}**	**1.33x 10^{07}**
LiF	**7.56 x 10^{06}**	**7.38x 10^{06}**
V	**8.25x 10^{06}**	**7.83x 10^{06}**
Mn	**1.11x 10^{07}**	**1.01x 10^{07}**
Mo	2.16x 10^{06}	1.64x 10^{06}
Zn	2.16x 10^{06}	1.76x 10^{06}





Experimental vs Simulated Neutron yield at various proton energies.

Experimental measurements are extrapolated from Neutron Dose rate meters and activation foil measurement.

Simulations for low Z, low proton energies
Depends heavily on Physics models, cross section libraries.

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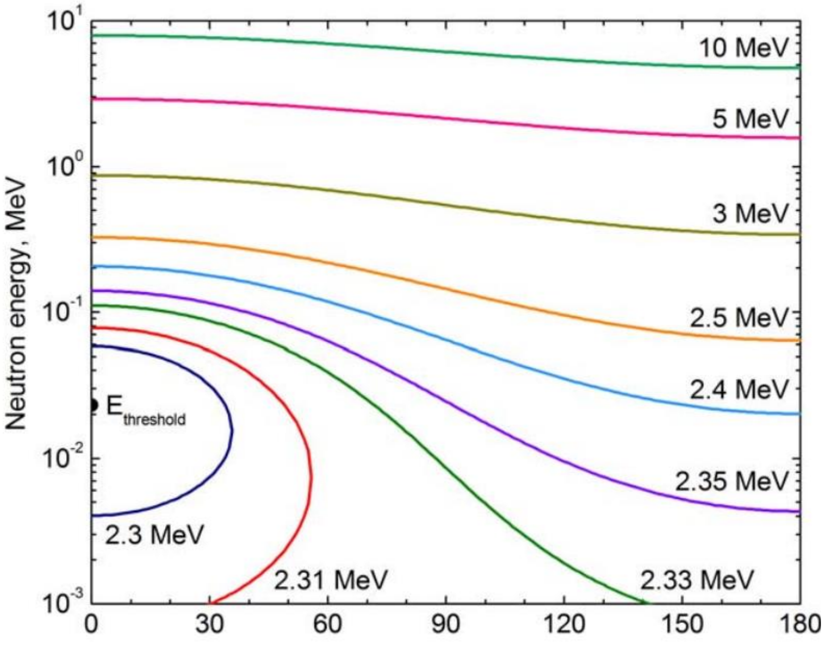
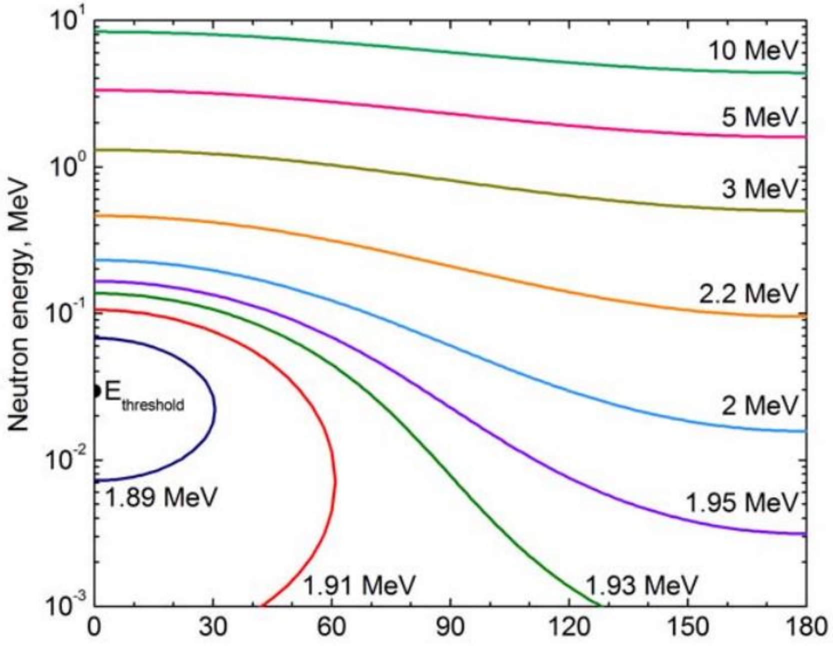
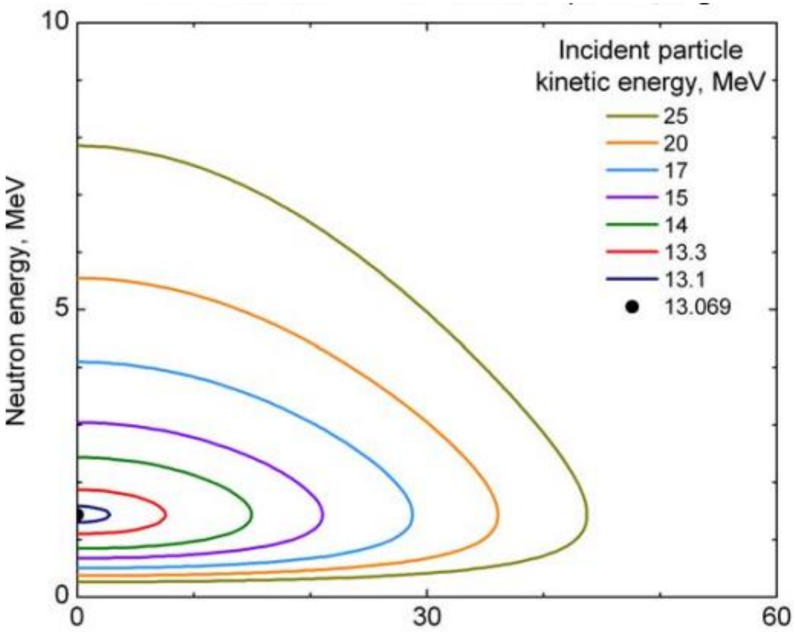
3 Major Reaction Channels with highest Neutron Yield



$^{9}Be(p,n)^{9}B$



$^{7}Li(p,n)^{7}Be$



$^{1}H(^{7}Li,n)^{7}Be$

- 3 Major Neutron producing targets.
- Quasi Monoenergetic neutron of various energies are available.
- Possibilities to study inverse kinematics

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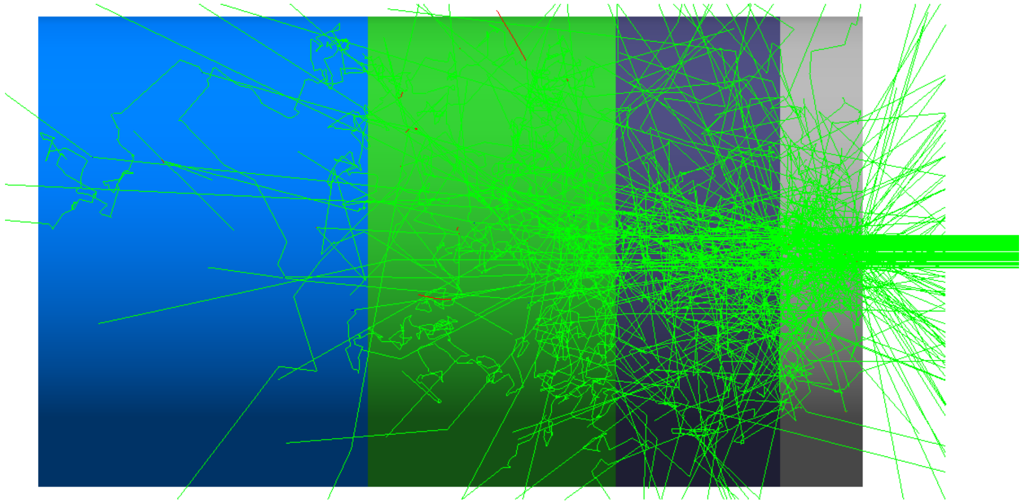
Chichester, David L.. "Production and applications of neutrons using particle accelerators." , Nov. 2009. https://doi.org/10.2172/1169209

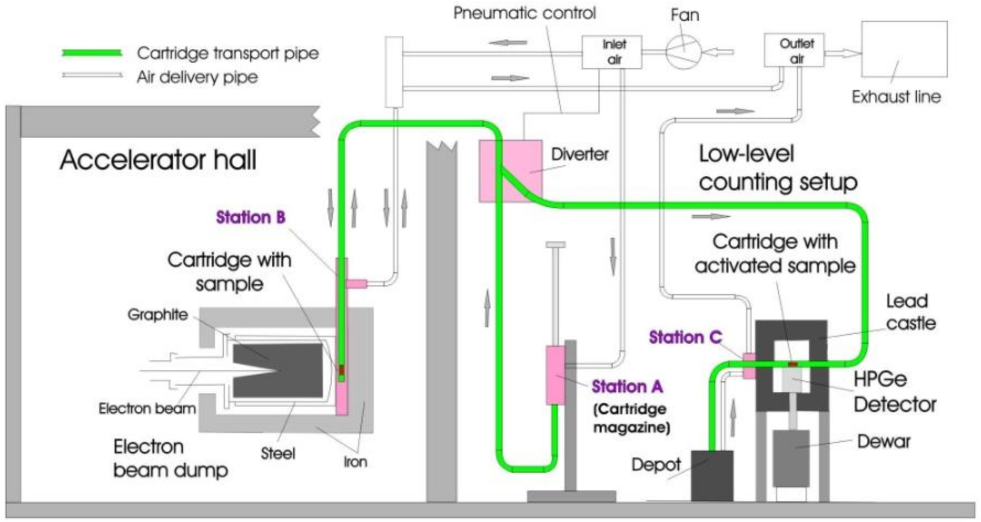
Future Developments in NESSA

Thermalized Beam line



Optimal moderator configuration under study

Rabbit system for activated samples



Goal : $T_{1/2}$ < 10 sec.

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NESSA in 2026-2027

- Procurement of High Yield D-T Generator – 1 x 10^{10} n/s : **20 X increase**.
  - Funded by Swedish Energy Agency.
  - Procurement under process.

- Tandem Laboratory: More Standardized and dedicated neutron beam line with multiple energies and angular distribution.

- Establishment of reference neutron fields and cross calibration with established facilities.

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Summary

•**NESSA:** being built as an intermediate-level, complete neutron beamline facility to serve the full spectrum of neutron physics research.

- ✓ **Absolute neutron yield calibrated:** $Y = (4.33 \pm 0.36) \times 10^8$ n/s via ^{93}Nb activation
- ✓ **First SEE measurement confirmed:** Neutron-induced bit-flip errors observed in chips — NESSA is operational for electronics irradiation.
- ✓ **Fission chamber response validated:** R_{235}/R_{238} spectral index measured;
- ✓ **First nuclear data result from NESSA:** $^{113}In(n,2n)$ isomeric yield ratio measured — IYR = 3.82 ± 0.47 at 14.7 MeV, first measurement at this facility.

•NESSA is open, and we would be genuinely glad to **collaborate, share beam time, and do good science together.**

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Thank you
&
Question??

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