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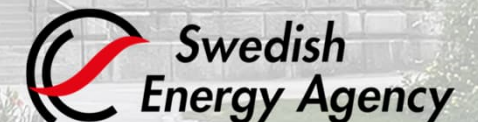
# NESSA: NEutron SourceS at UppSAla

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

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*15<sup>th</sup> Nordic Meeting in Nuclear Physics*



# 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*

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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*

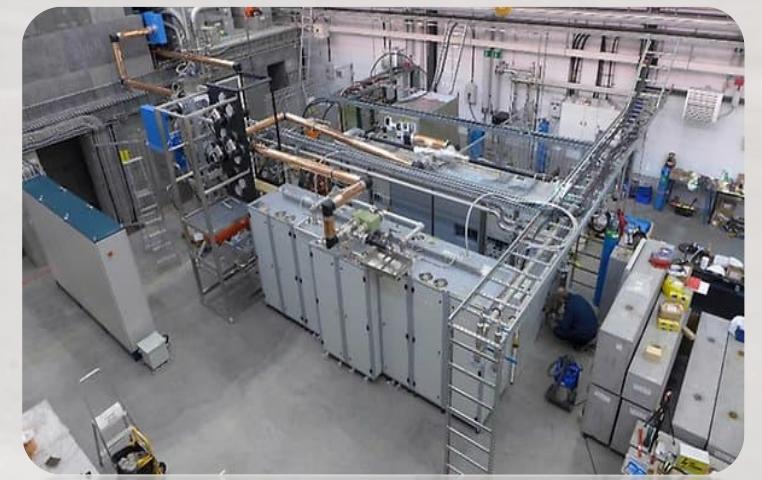
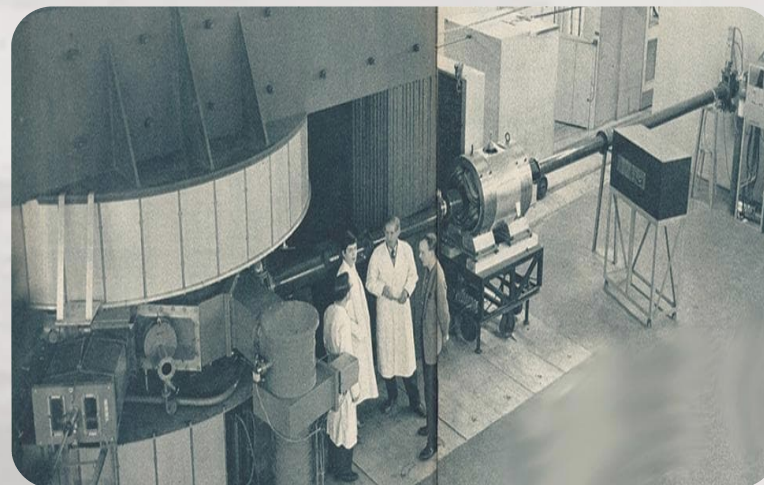
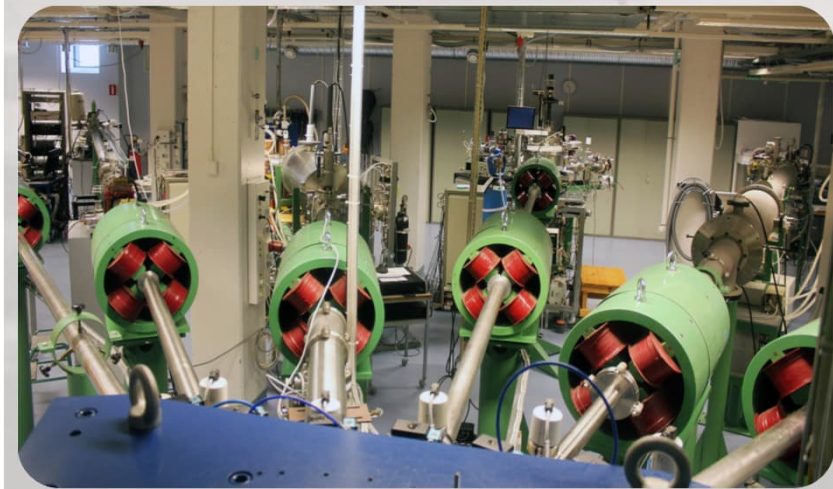
**TANDEM** Laboratory Ion beams for materials research.

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.

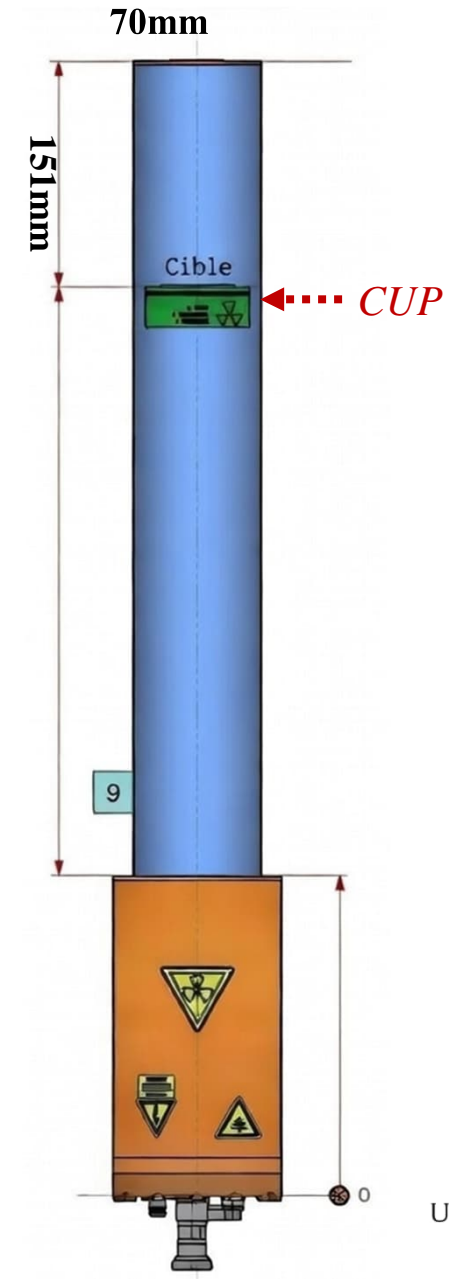
\*H. Sjostrand et al.; Total Monte Carlo Evaluation for Dose Calculations, RPD, 2013



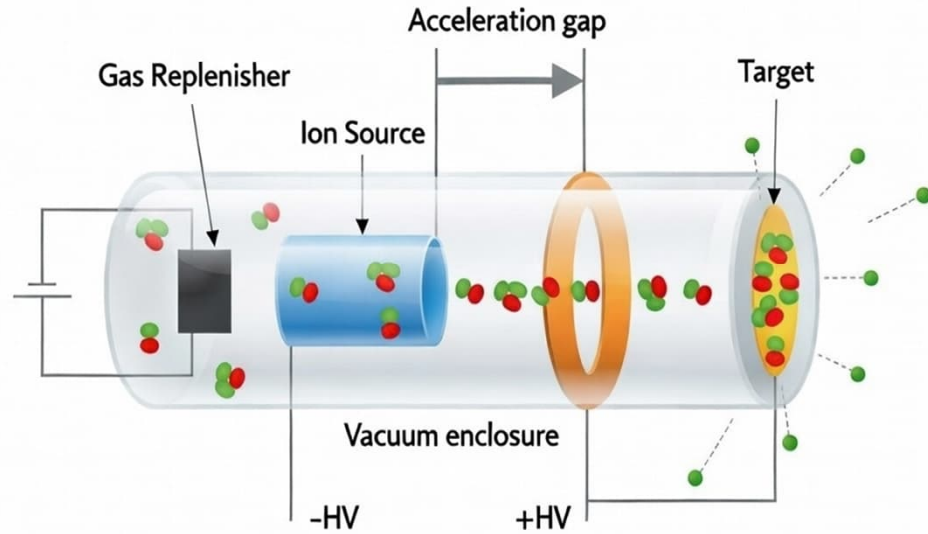
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# Key Technical Specifications of the Neutron Generator

- Peak neutron yield:  $4.7 \times 10^8 \text{ n/s/4}\pi \text{ sr}$
- 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  $\mu\text{s}$**
- Pulse timing controlled via proximity box; **external trigger compatible**



# 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).



# Neutron Flux: Measurement Parameters and Notation

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

## Parameter Definitions:

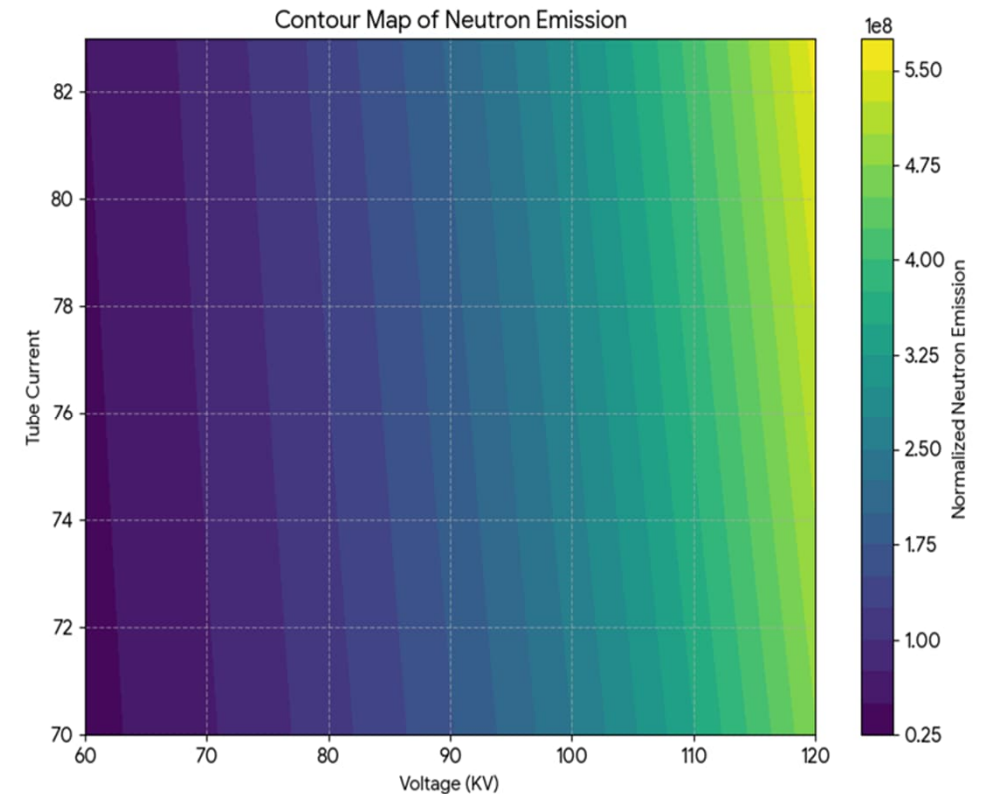
$R_{Rep}$  — Gas replenisher resistance (m $\Omega$ ). controlling gas pressure and D-T fuel flow.

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

$I_{tube}$  — Tube current ( $\mu$ A). directly proportional to the neutron production rate.

At 120 KV-  $V_{HV}$ , 80  $\mu$ A-  $I_{tube}$  & 1670 m $\Omega$ -  $R_{rep}$

$$Y = 4.4 \times 10^8 \text{ n/s.}$$



# Associated Detector Systems and Instrumentation

- Micro-fission chamber ( $\mu$ FC) for real-time beam flux monitoring — both  $^{235}\text{U}$  and  $^{238}\text{U}$  variants available.
- NaI(Tl) & LaBr<sub>3</sub> scintillators for prompt gamma-ray spectroscopy.
- EJ-301 liquid scintillator for fast-neutron detection and n/ $\gamma$  discrimination.
- High Efficiency HPGe system for gamma spectrometry.
- WENDI extended energy neutron dose-rate meter

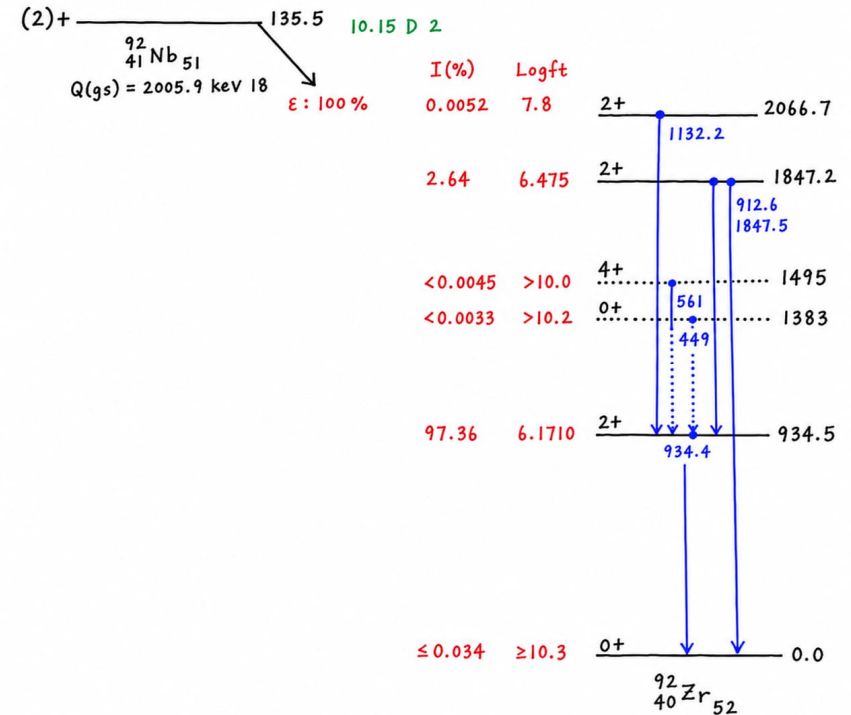
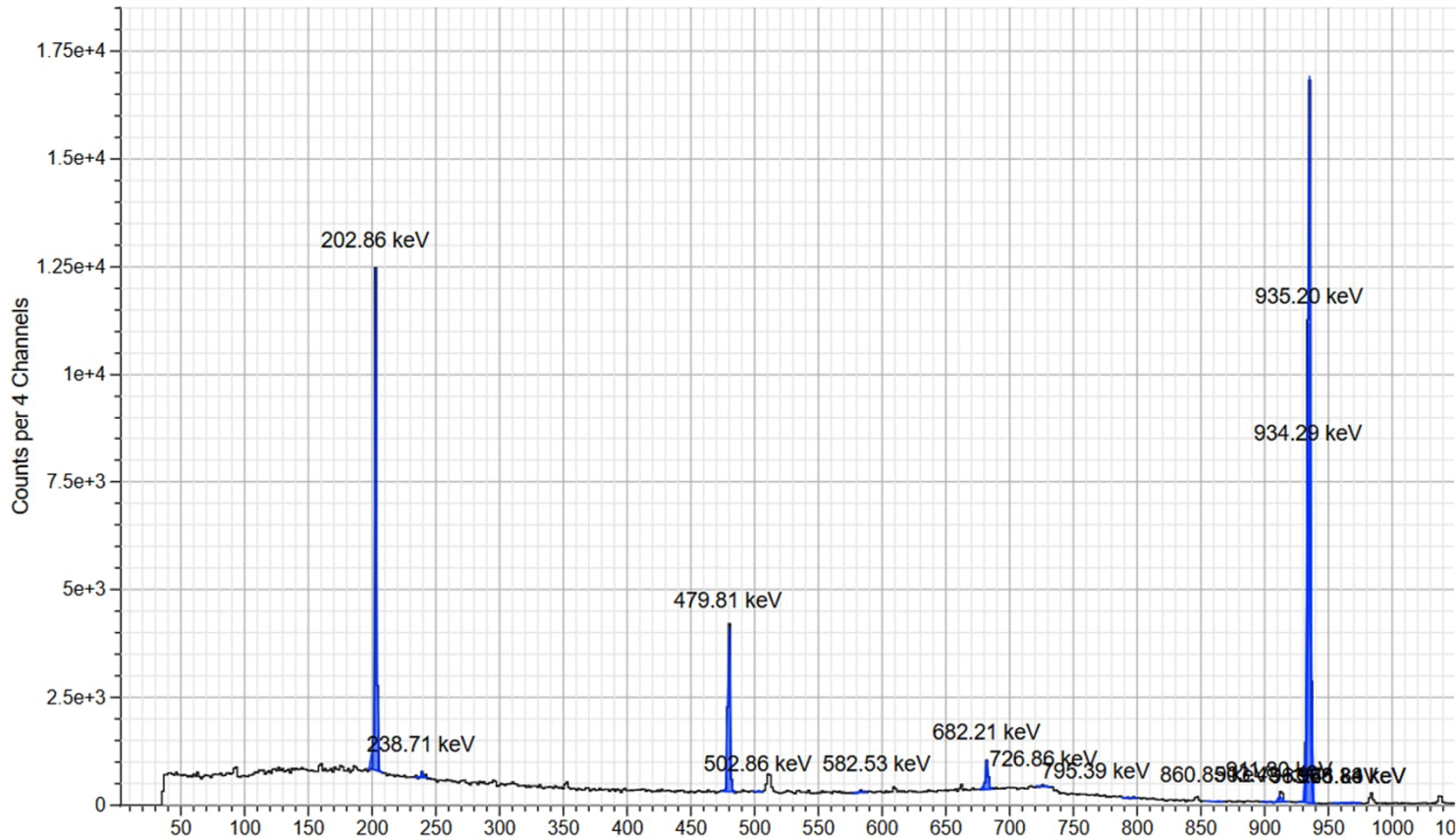


*Building up the lead castle for HPGe in NESSA*



*Fission Chambers and Liquid scintillators placed in closed user position*

# $^{93}\text{Nb}$ Activation Foil Dosimetry and Flux Monitoring



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



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

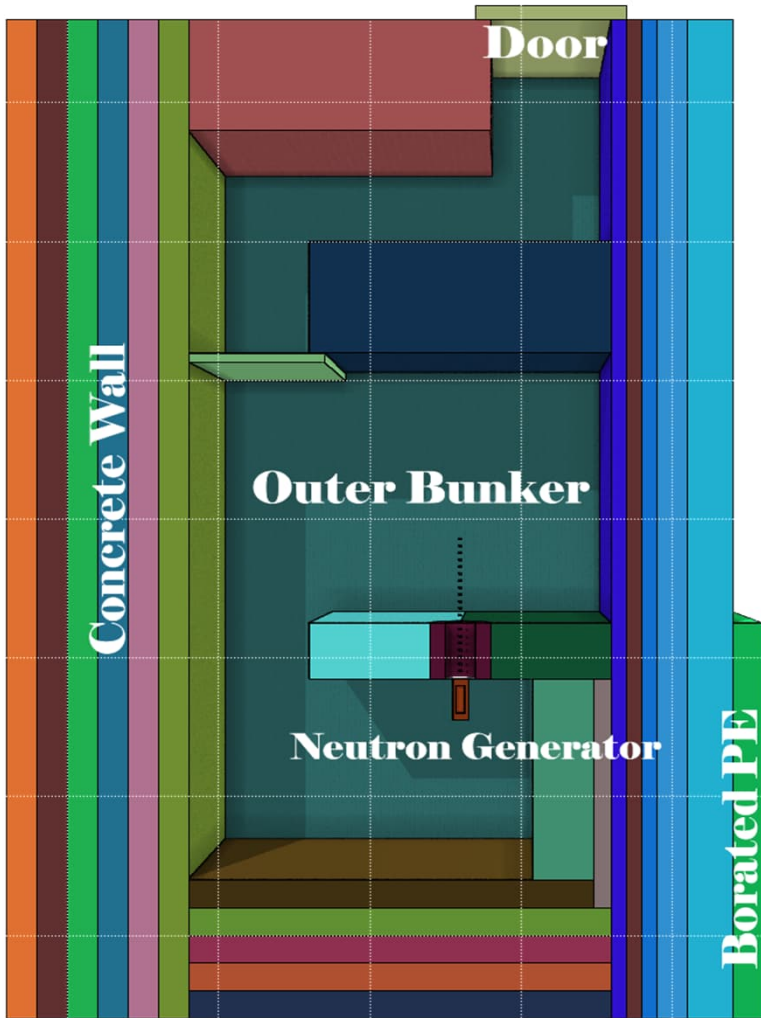
$$Y = (4.33 \pm 0.36) \times 10^8 \text{ n/s}$$

D. NEUTRON YIELD CALCULATION		
Measured flux $\Phi$ at foil (n/cm <sup>2</sup> /s)	1,510E+06	n/cm <sup>2</sup> /s
Flux uncertainty $\delta\Phi$ (n/cm <sup>2</sup> /s)	1,001E+05	n/cm <sup>2</sup> /s
$r^2$ (cm <sup>2</sup> )	22,563	cm <sup>2</sup>
<b>Yield <math>Y_{\text{point}}</math> (n/s) — point source</b>	<b>4,282E+08</b>	n/s
Yield $Y_{\text{geom}}$ (n/s) — geom corrected	4,330E+08	n/s
<b>Yield <math>Y_{\text{final}}</math> (n/s) — full correction</b>	<b>4,325E+08</b>	n/s
E. UNCERTAINTY ON NEUTRON YIELD		
$\delta Y/Y$ from flux $\delta\Phi/\Phi$	6,630%	fraction
$\delta Y/Y$ from distance $\delta r/r$ ( $\times 2$ )	1,000%	fraction
$\delta Y/Y$ from anisotropy $\delta A/A$	5,000%	fraction
$\delta Y/Y$ from $C_{\text{geom}}$	0,300%	fraction
<b>Combined <math>\delta Y/Y</math></b>	<b>8,370%</b>	fraction
<b>Absolute uncertainty <math>\delta Y</math> (n/s)</b>	<b>3,620E+07</b>	n/s

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

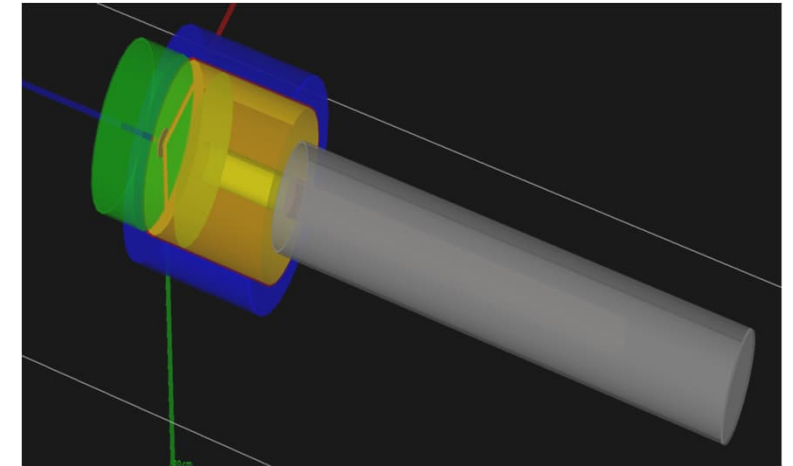


# Monte Carlo Modelling of the complete beamline



*3D reconstruction of NESSA facility*

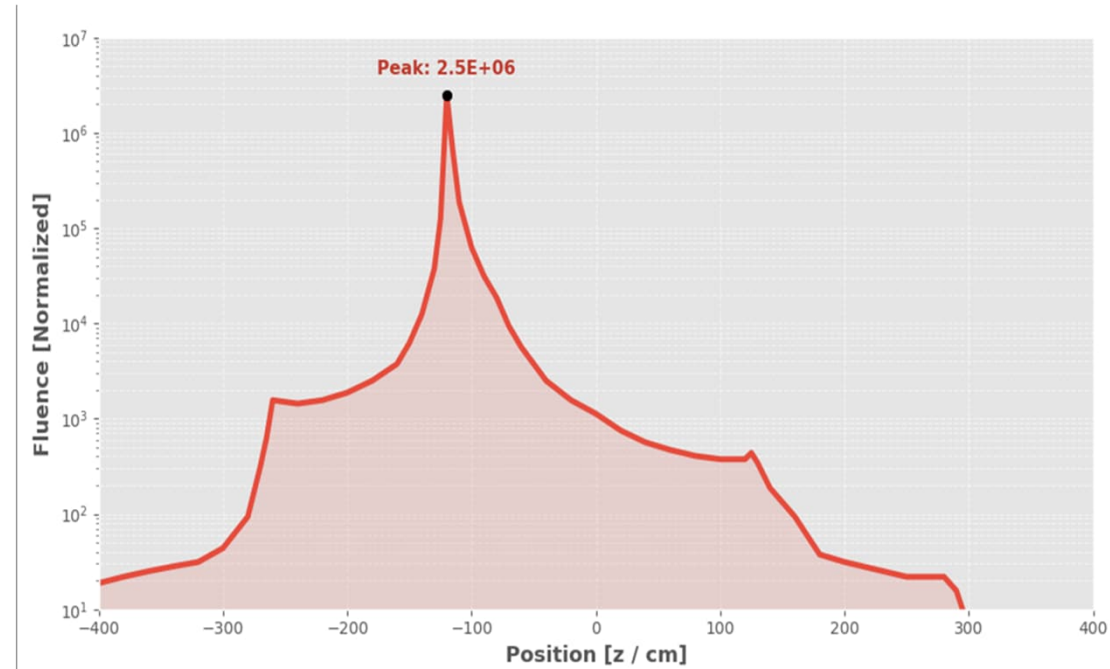
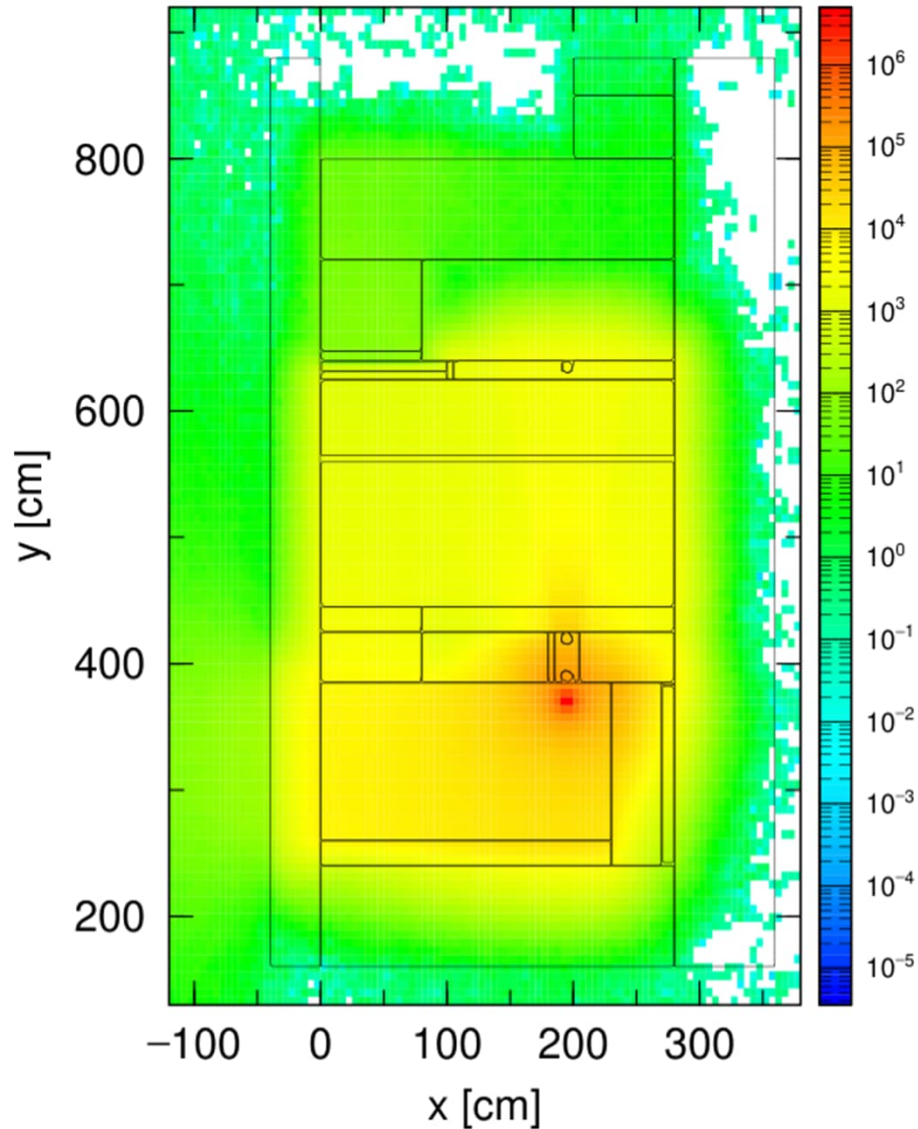
- Major Monte Carlo codes have been used to reconstruct complete NESSA geometry and detector responses.
- *Geant4. FLUKA. MCNP. PHITS & SERPENT.*
- Activation analysis of different structural materials, air activation.
- Neutron Spectrometry and dosimetry at different irradiation positions.
- Intercomparison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



*Reconstruction of HPGe detector*



# Simulated Neutron Fluence

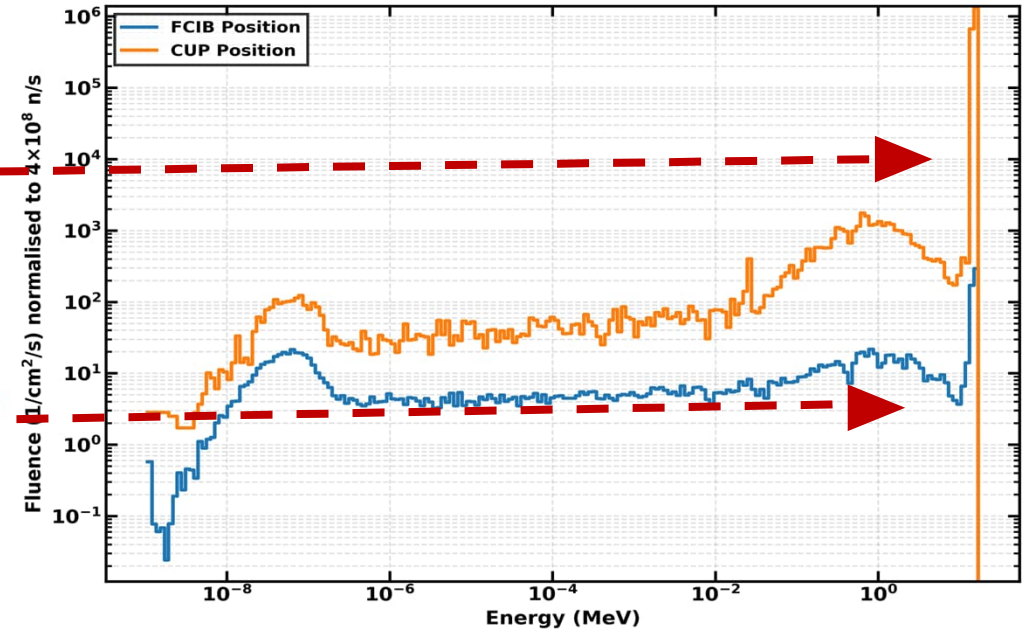
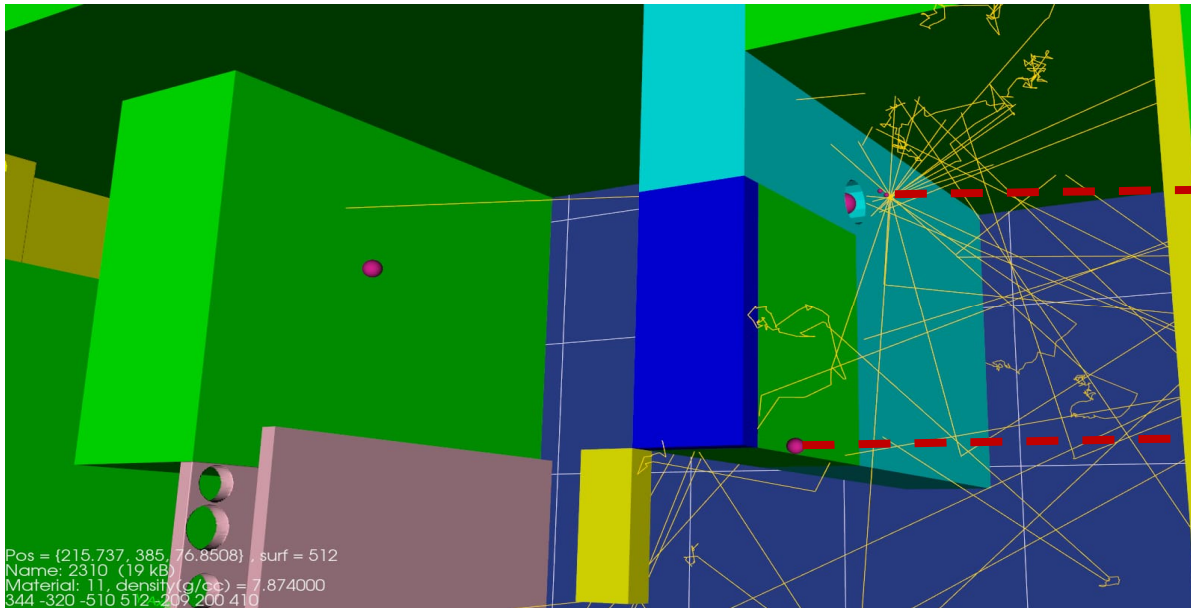


- Characterization of Neutron fluence and spectra through out the beam hall.
- Maximum flux at CUP is  $2.46 \times 10^6$  n/cm<sup>2</sup>/sec.
- Important for detector characterization. activation analysis and safety report.

*Neutron Fluence Map in NESSA bunker  
using PHITS*



# Characterization of Neutron Spectra



Location / Energy Range	Fluence (1/cm <sup>2</sup> )	%	Notes
<b>CUP Location</b>			
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)
<b>FCIB Location</b>			
Thermal (<10 eV)	2.14E+03	<b>25.06</b>	Room-return thermal
10 eV - 100 keV	1.91E+03	22.40	Epithermal region
Fast (≥100 keV)	4.49E+03	<b>52.53</b>	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.



# Fission Chamber response in NESSA

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

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

\* CUP is about 4 cm from the neutron emitting target

\*\* FCIB is about 130 cm from the neutron emitting target



*Fission chamber in irradiation positions*



# Gamma Ray in the neutron field: Simulation Results

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

Prompt (during beam-on)     Delayed (post beam-off, activation)

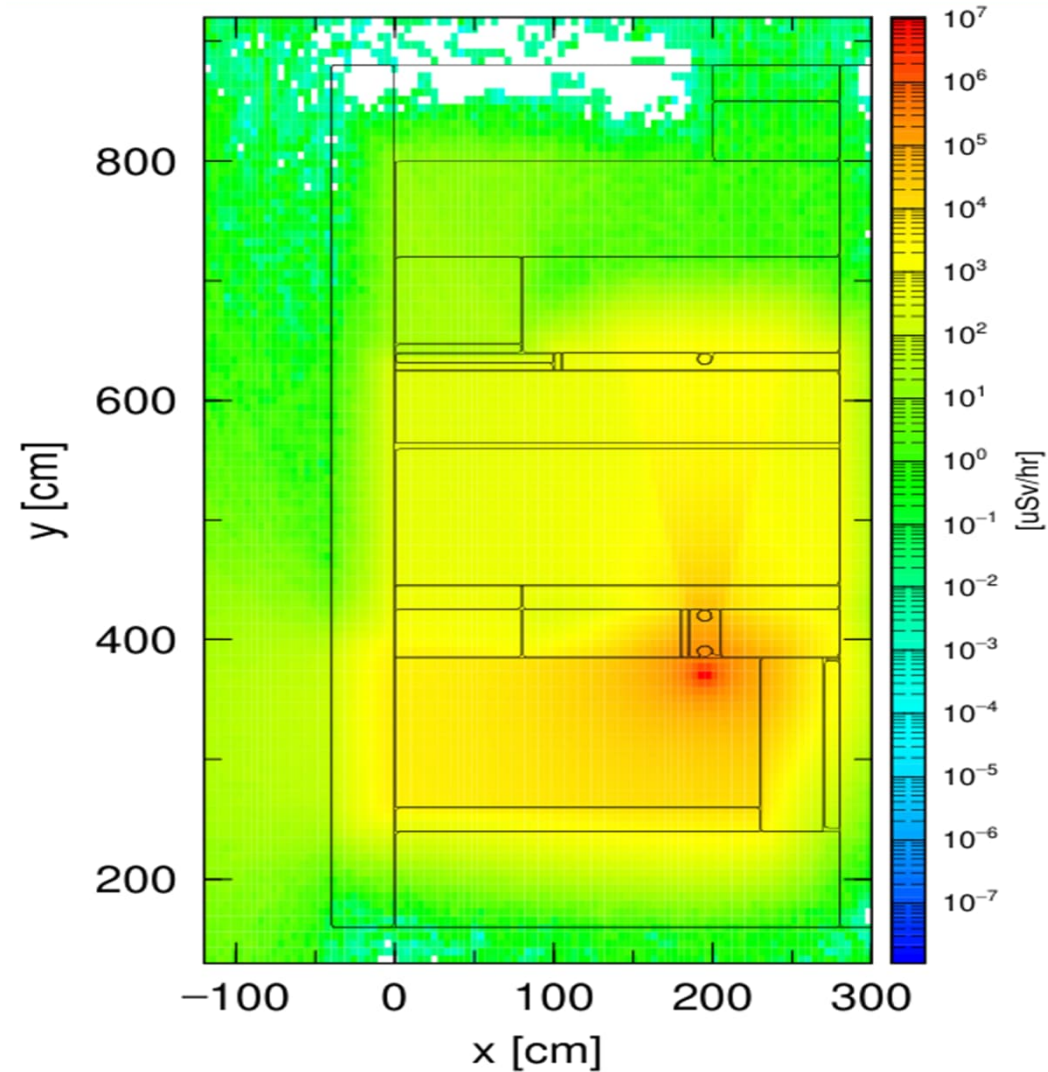
**SHORT-LIVED** minutes — hours

Isotope	$T_{1/2}$	Reaction	$\gamma$ (keV)
<b>V-52</b>	3.74 min	$V-51(n,\gamma)$	<b>1434.1 keV</b>
<b>Al-28</b>	2.24 min	$Al-27(n,\gamma)$	<b>1778.9 keV</b>
<b>Mg-27</b>	9.46 min	$Al-27(n,p)$	<b>843.8 keV</b>
<b>C-11</b>	20.4 min	$C-12(n,2n)$	<b>511.0 keV</b>
<b>Mn-56</b>	2.58 h	$Fe-56(n,p)$	<b>846.8 keV</b>

- 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.

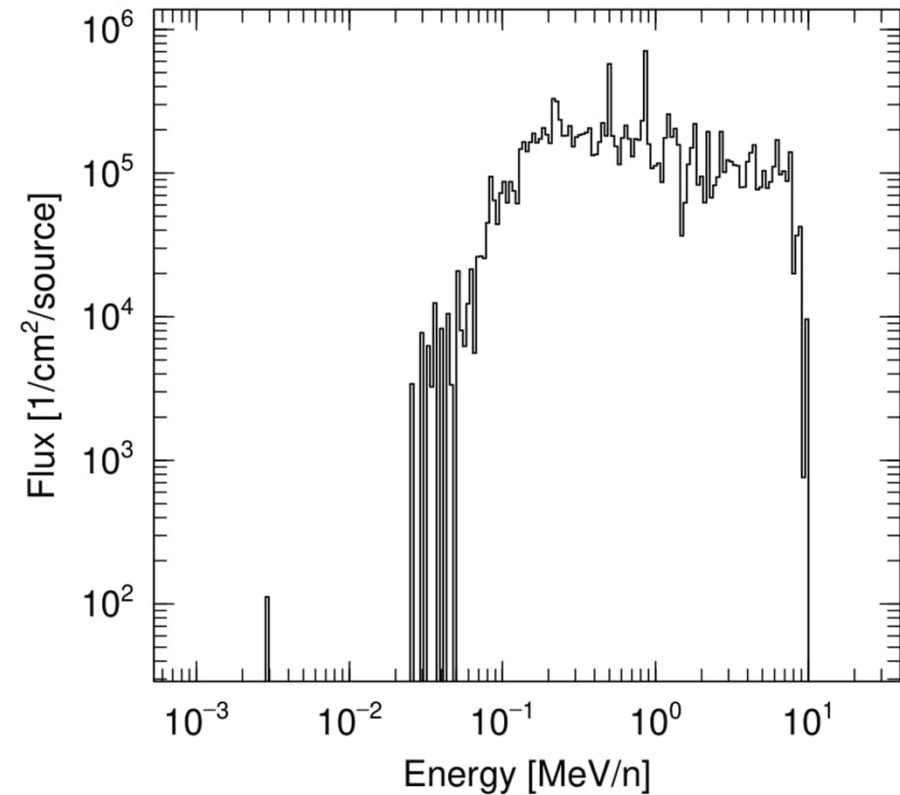


# Gamma Ray in the neutron field



*Distribution of gamma dose rate in source plane using PHITS*

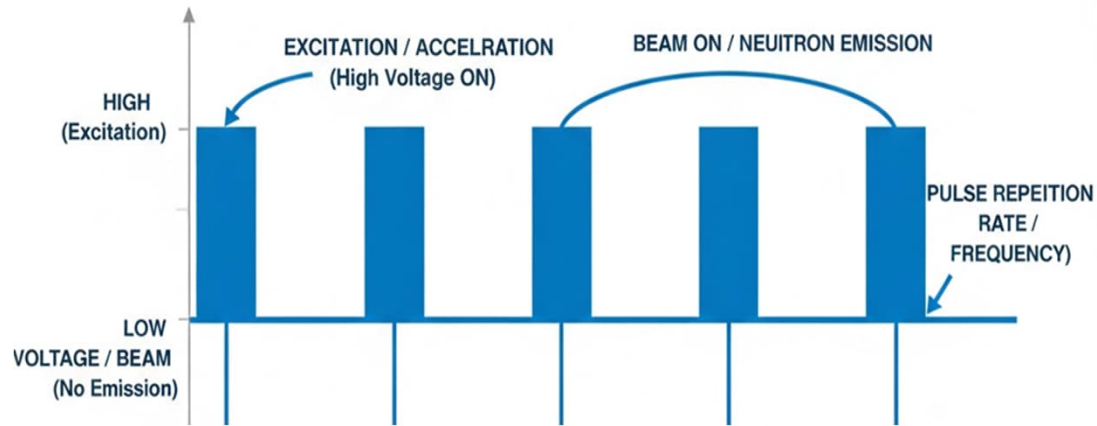
- Dose rate near the closest user position can reach 10 Sv/h.
- Wide distribution of energies. Can reach up to 10 MeV.
- Dose rate outside bunker is  $< 1\mu\text{Sv/h}$



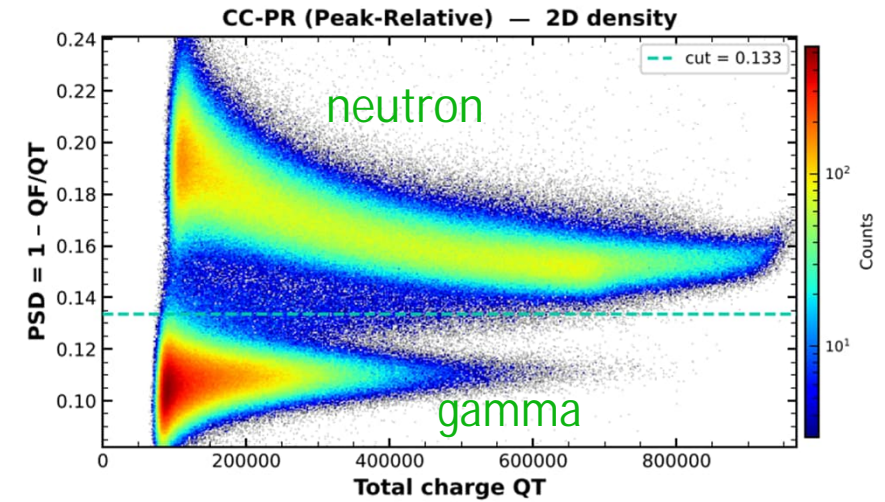
*Simulated Prompt  $\gamma$  spectra at CUP using PHITS*



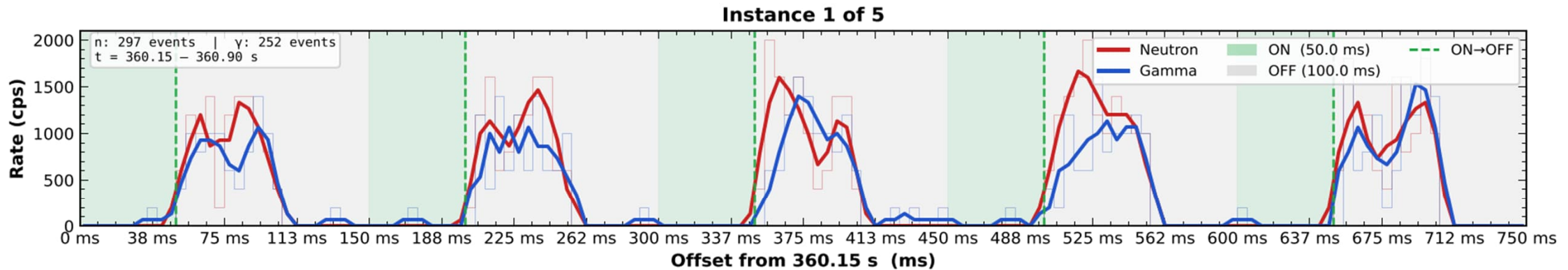
# Liquid Scintillator in Pulse Mode : Die-Away Phase



*Neutron Generator in Pulse Mode*



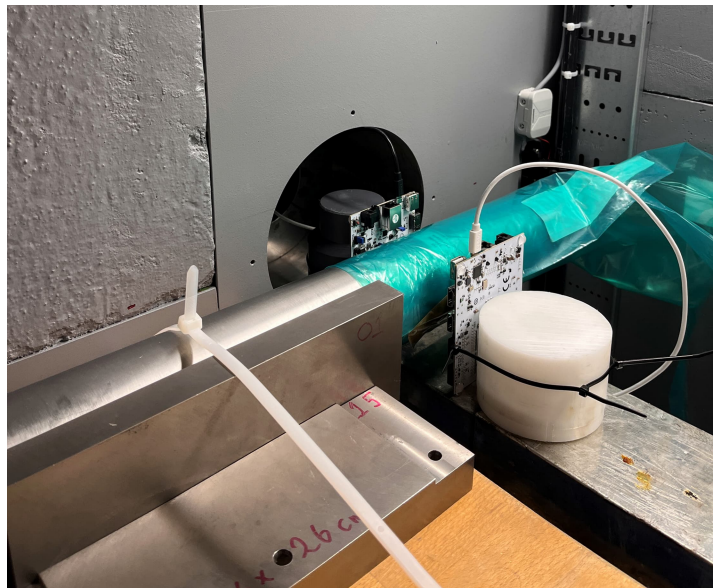
*n/γ discrimination*



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

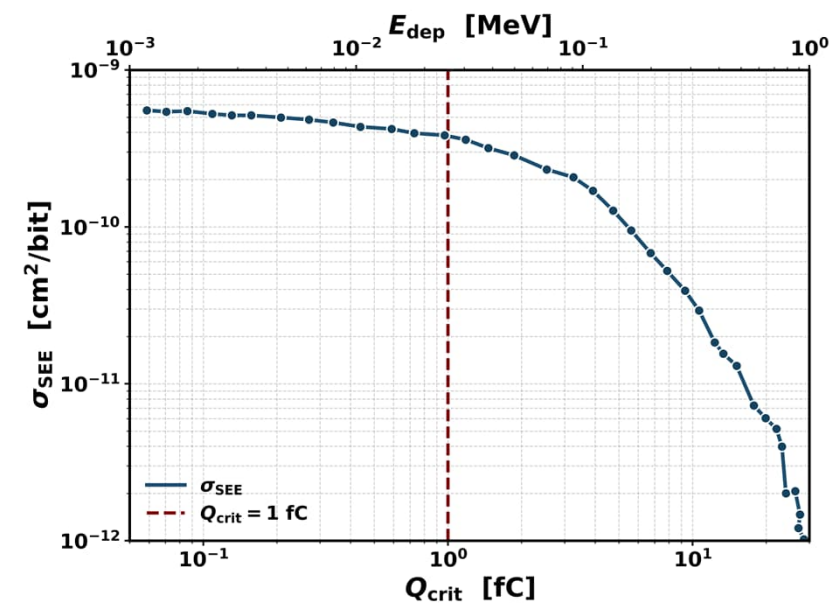


# Studying SEE and Electronics Damage at NESSA



Irradiation of electronic chips at NESSA

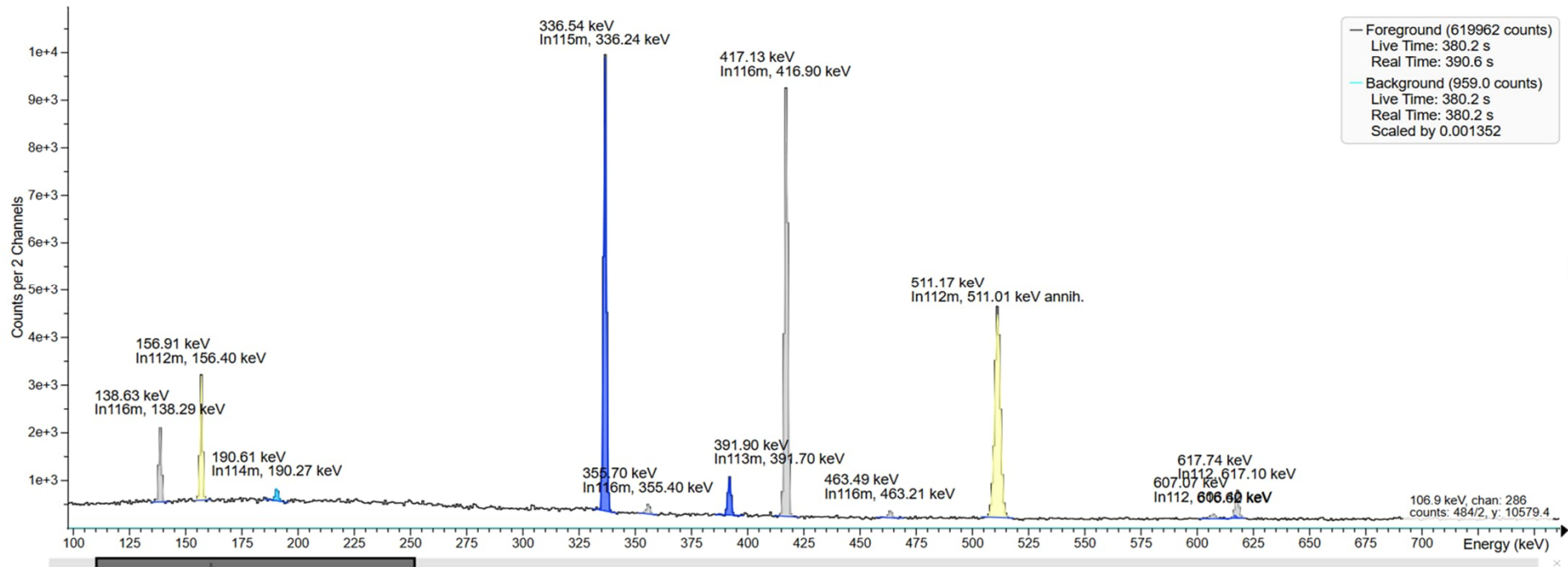
- **Major Goal of NESSA:** studying electronics damage like Single Event Error/Upset(SEE).
- Direct implication in Space Science. Reactor Electronics. Aviation Safety.
- Irradiated two chip configurations (Linear Feedback Shift Register and Fast Fourier Transform)
- Observed **single bit-flip errors** 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



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



## $^{115}\text{In}$ reactions (95.7% abundant):

- $(n,2n)^{114\text{m}}\text{In}$  — threshold 10.4 MeV, 49.51 d, 190.27 keV — absolute yield calibration reaction:  $1210 \pm 71$  mb
- $(n,\gamma)^{116\text{m}}\text{In}$  — thermal capture, 54.29 min, 1097/1293 keV — the room-return thermal contribution: [Simulation benchmark](#)
- $(n,n')^{115\text{m}}\text{In}$  — threshold 0.34 MeV, **4.486 h**, 336 keV — inelastic threshold detector :  $T_{1/2} = 4.353 \pm 0.224$  h.

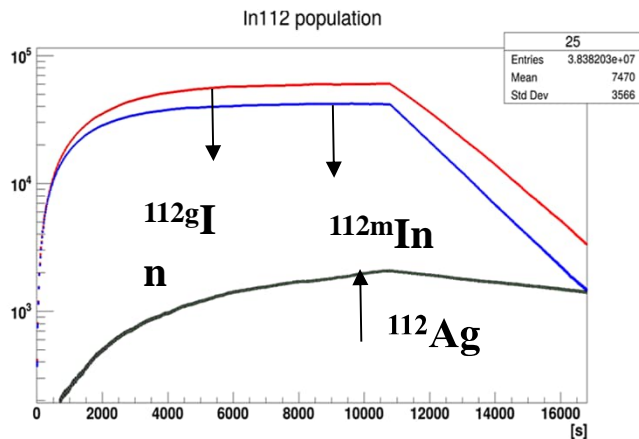
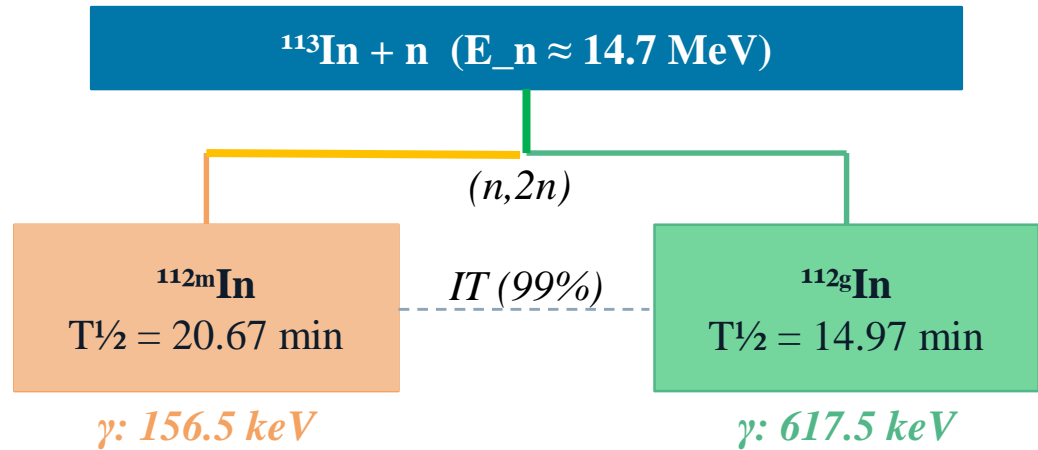
## $^{113}\text{In}$ reactions (4.3% abundant):

- $(n,2n)^{112}\text{In}$  — threshold 9.2 MeV, dual isomers at 156.5 617.5 keV — [IYR measurement](#)



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

## Decay Scheme



⚠  $^{112}\text{Ag}$  interferes  
617.5 keV overlap  
 $^{115}\text{In}(n,\alpha)$

## Measurement & Analysis Chain

- 1 Foil in 14.7 MeV neutron beam  
 $Y \approx 4.3 \times 10^8$  n/s ( $^{93}\text{Nb}$  calibration)
- 2 156.5 keV ( $^{112\text{m}}\text{In}$ ) + 617.5 keV ( $^{112\text{g}}\text{In} + ^{112}\text{Ag}$ )  
Timed series: cool, count, repeat
- 3 Source-term equations for all phases:  
irrad.  $\rightarrow$  cooling  $\rightarrow$  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



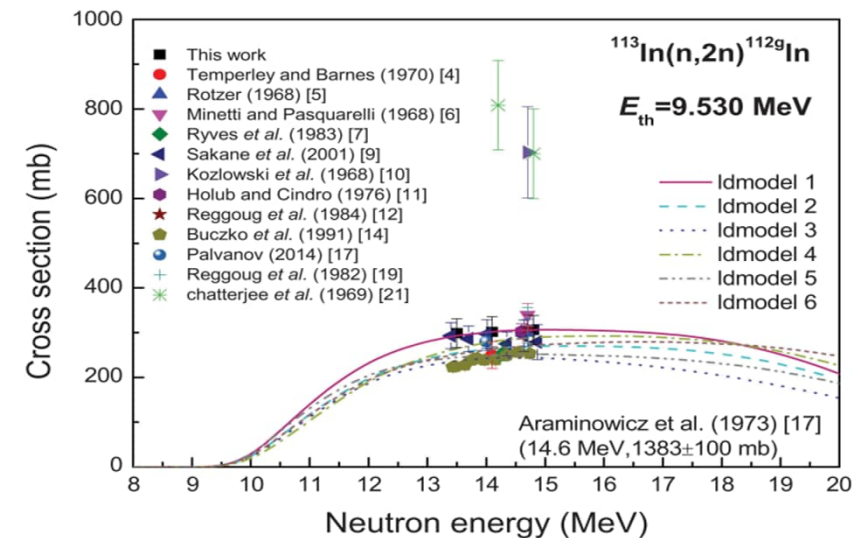
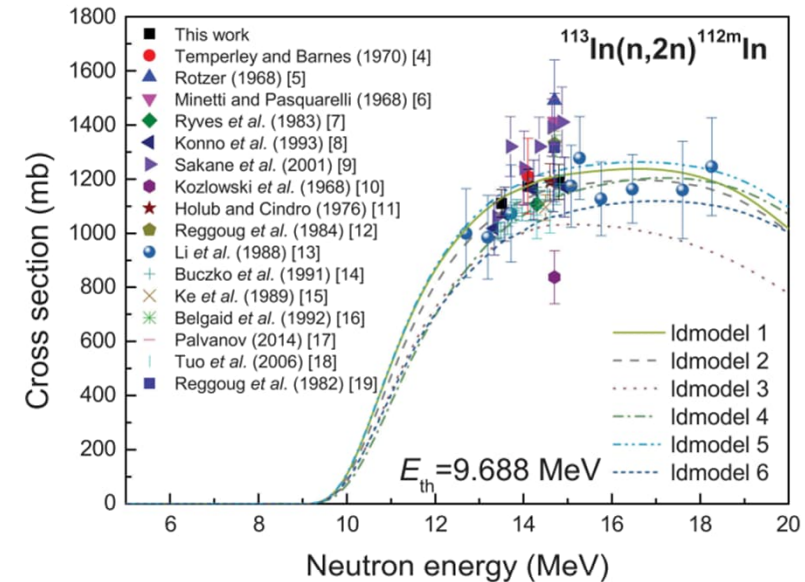
# $^{113}\text{In}(n,2n)$ IYR — Results at 14.7 MeV & Cross-Checks

Measured IYR ( $Y^m / Y^g$ ):  $3.82 \pm 0.47$

*\*\*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.



# 5 MV 15SDH-2 Pelletron facility for Neutron production



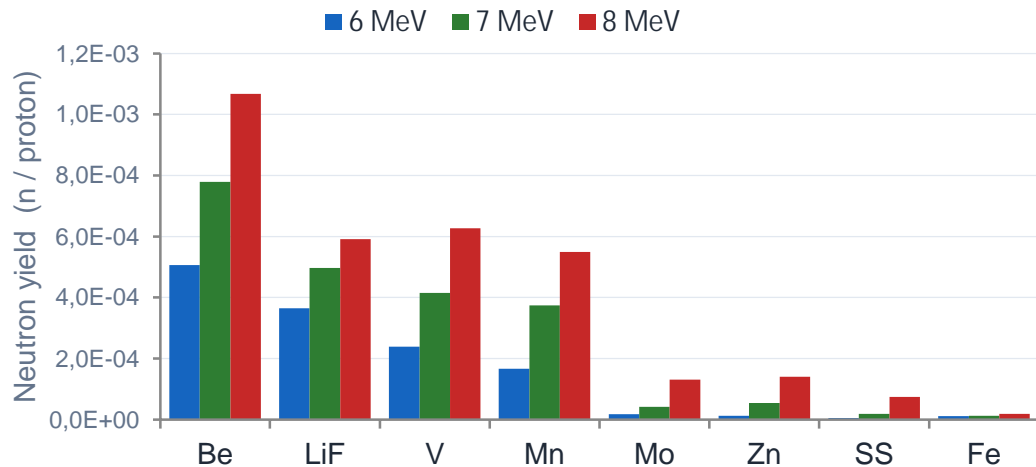
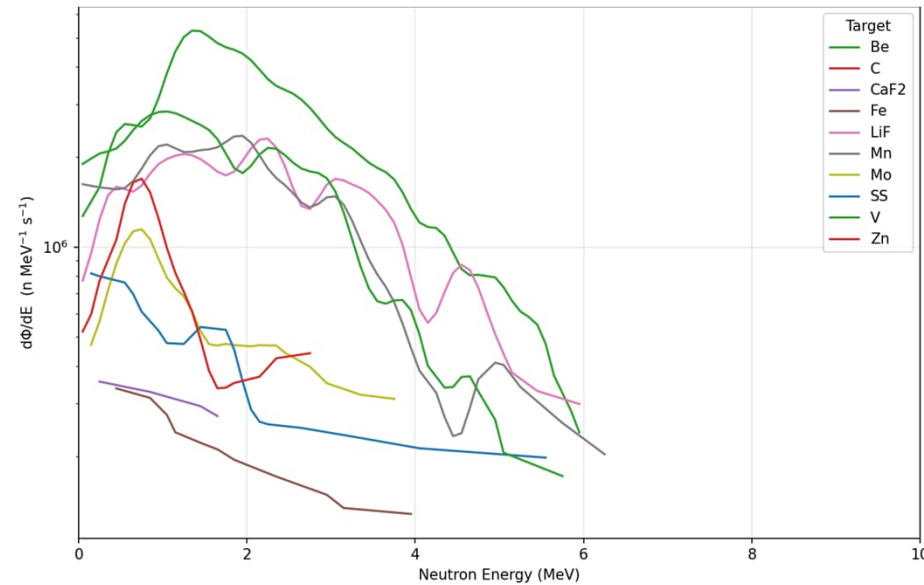
Target	Primary (p.n) reaction	Q (MeV)	Eth (MeV)
Be	${}^9\text{Be}(p,n){}^9\text{B}$	-1.85	2.06
LiF	${}^7\text{Li}(p,n){}^7\text{Be}$	-1.64	1.88
V	${}^{51}\text{V}(p,n){}^{51}\text{Cr}$	-1.53	1.56
Mn	${}^{55}\text{Mn}(p,n){}^{55}\text{Fe}$	-1.02	1.04
Mo	${}^{98}\text{Mo}(p,n){}^{98}\text{Tc}$	-2.47	2.50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



# 8MeV proton on different targets

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



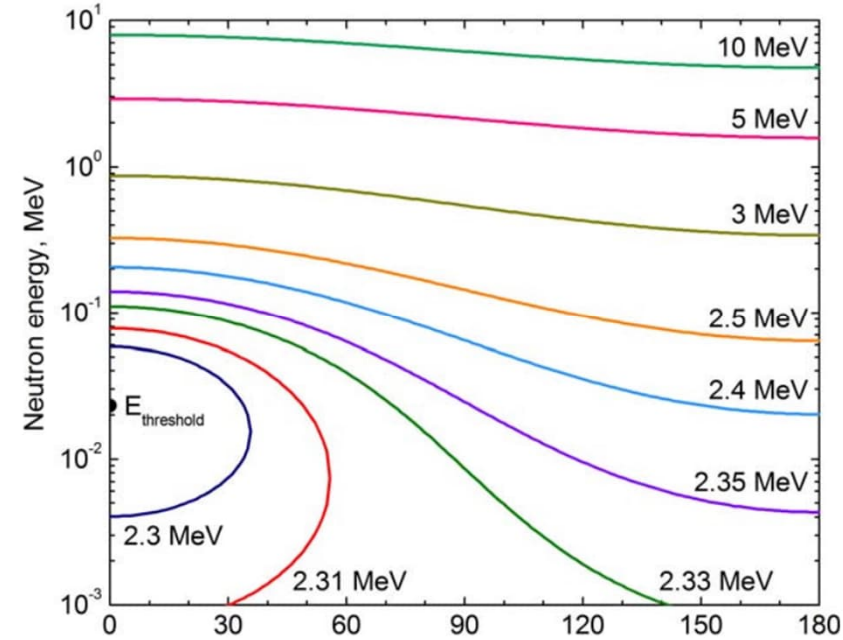
Experimental vs Simulated Neutron yield at various proton energies.

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

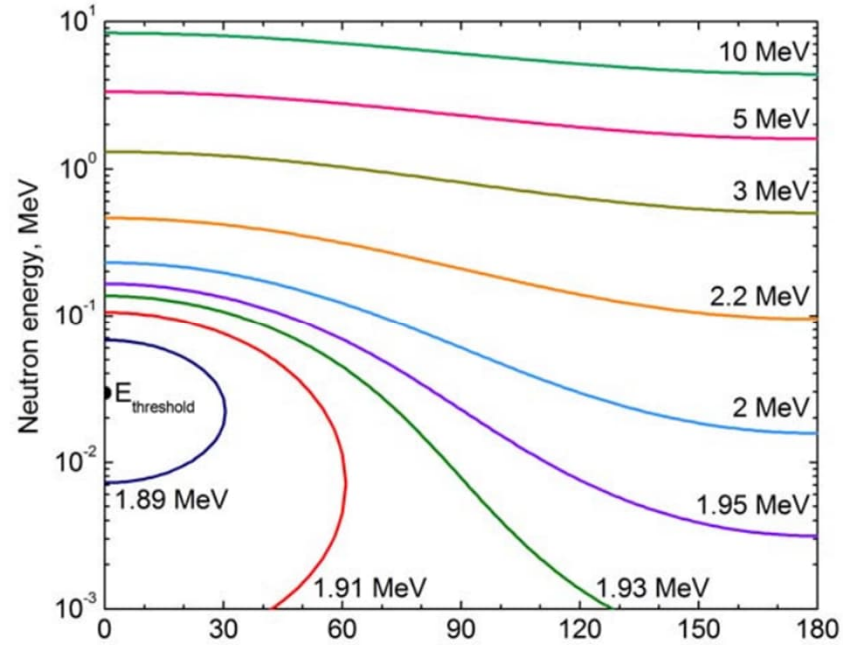
Simulations for low Z, low proton energies  
Depends heavily on Physics models, cross section libraries.



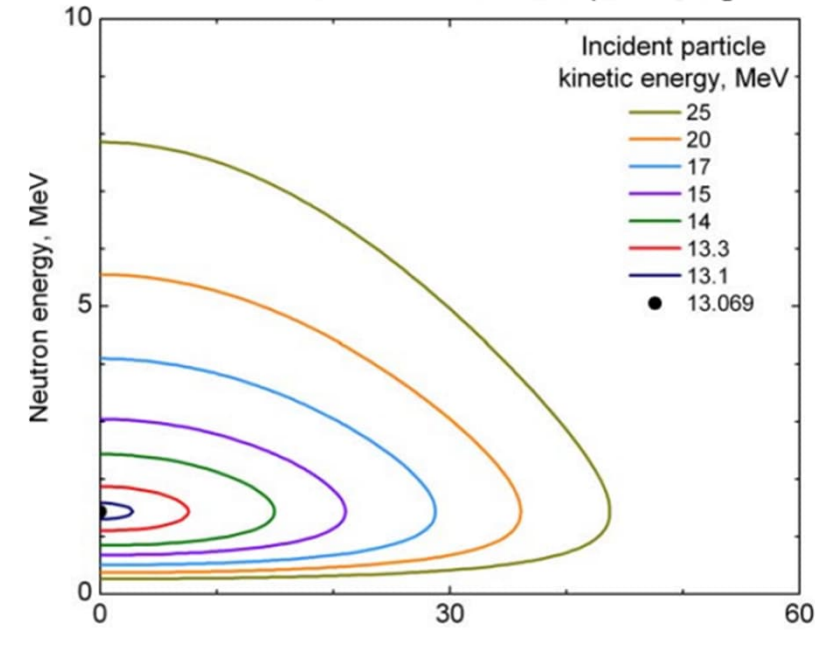
# 3 Major Reaction Channels with highest Neutron Yield



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



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



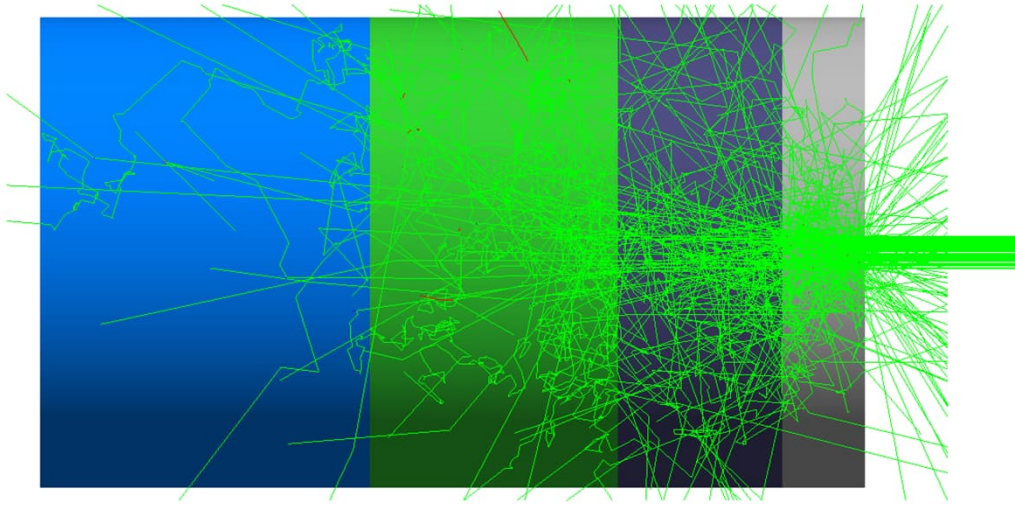
${}^1\text{H}({}^7\text{Li},n){}^7\text{Be}$

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



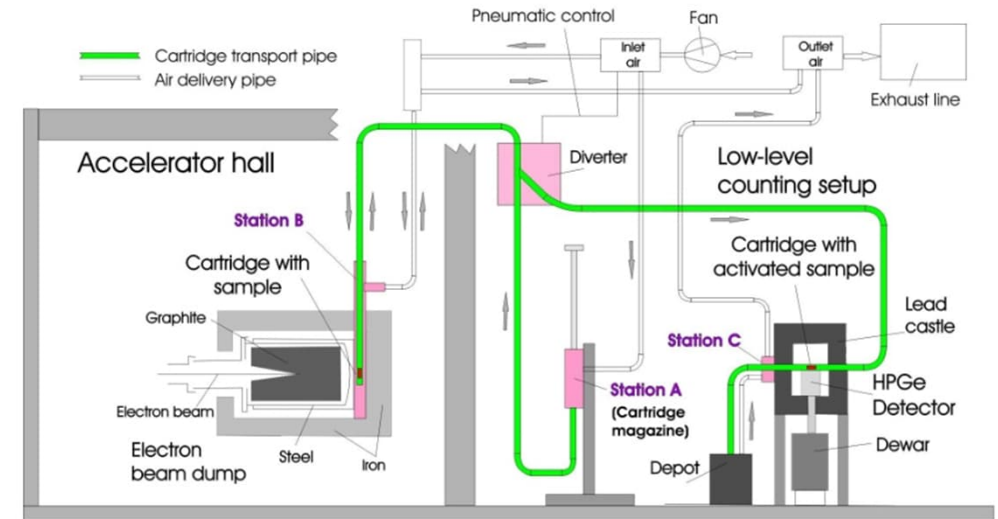
# Future Developments in NESSA

## Thermalized Beam line



Optimal moderator configuration under study

## Rabbit system for activated samples



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



- Procurement of High Yield **D-T Generator** –  $1 \times 10^{10}$  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.



# 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  $^{93}\text{Nb}$  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:**  $^{113}\text{In}(n,2n)$  isomeric yield ratio measured —  $\text{IYR} = 3.82 \pm 0.47$  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.**





UPPSALA DOMKYRKA

UPPSALA SLOTT

GAMLA UPPSALA MOUNDS

GAMLA UPPSALA CHURCH

GUSTAVIANUM

CAROLINA REDIVIVA

**Thank you  
&  
Question??**

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