



AmBeSim

Filippo Falezza

Theoretical  
Framework

Current Status

Primary  
Generator

Emerging  
Neutrons

Conclusion

## Simulation of a $^{241}\text{Am} - ^9\text{Be}$ neutron source using Geant4

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N. Curtis**  
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26<sup>th</sup> November 2025 - Neutron User Club @ NPL



# $^{241}\text{Am}$ - $^9\text{Be}$ Neutron source

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No accurate open source simulation - others are suboptimal

Long half life and stable flux over a 10 - 15 year working life

Plethora of uses:

- Metrology
- Education environment
- Neutron Activation Analysis for identification of unknown materials
- Calibration (dosimeters and detectors)
- Industrial (e.g. well logging via  $^1\text{H}(n,\gamma)^2\text{H}$ )



# Reaction of Interest

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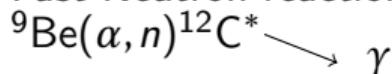
Mixture of  $\text{AmO}_2$  and  ${}^9\text{Be}$  powder — Stainless-steel

> 99%  ${}^{241}\text{Am}$

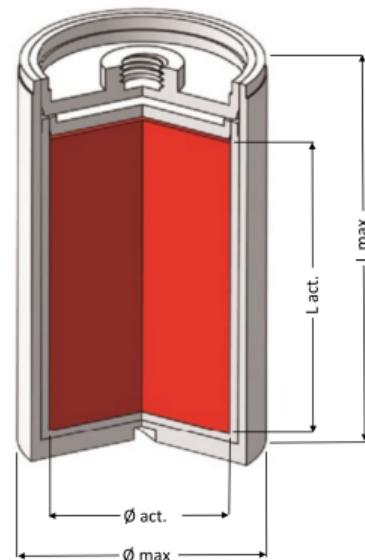
${}^{241}\text{Am}$   $\alpha$  emission:

Energy (keV)	Intensity (%)
5388	1.66
5442.80	13.1
5485.56	84.8
5511.5	0.225
5544.5	0.37

Fast Neutron reaction: Q value: 5.702 MeV



${}^{12}\text{C}$  can be either in ground, 1<sup>st</sup>, 2<sup>nd</sup> (Hoyle) excited state



Source drawing, AmBe mixture (red) encased in steel [Raims Ltd]



# Reactions of interest

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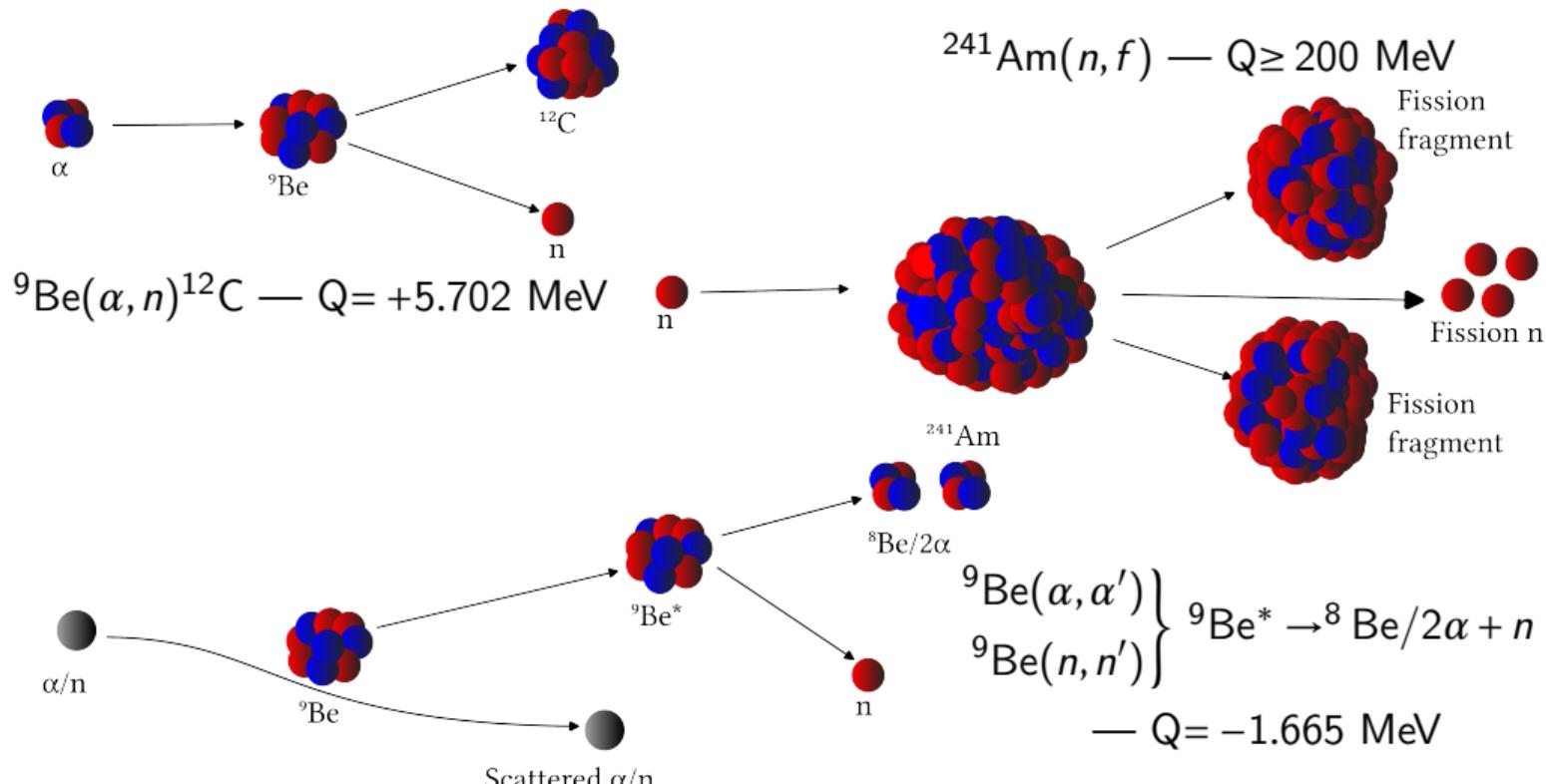
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# Fast reaction

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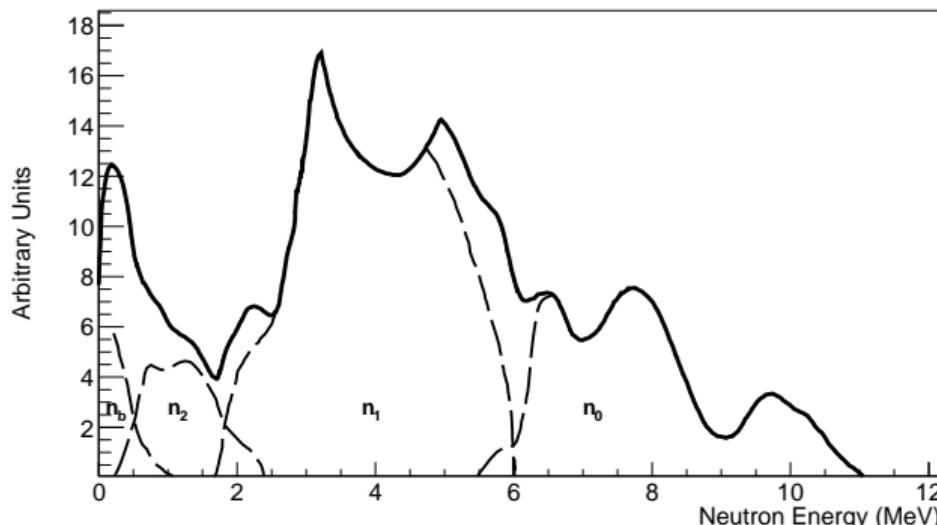
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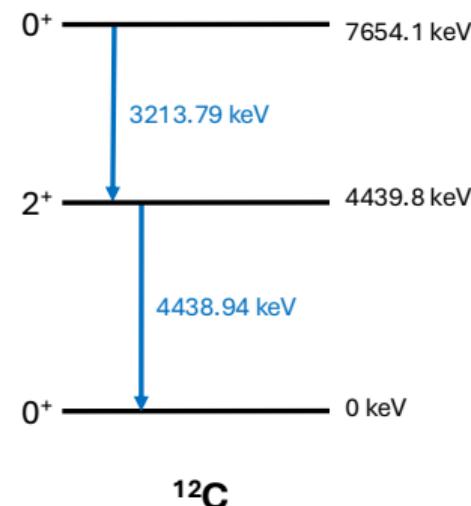
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AmBe neutron distribution per  $^{12}\text{C}$  state [Geiger-Van Der Zwan 1975]



$^{12}\text{C}$  states - ground, 1<sup>st</sup>,  
2<sup>nd</sup> [NNDC]



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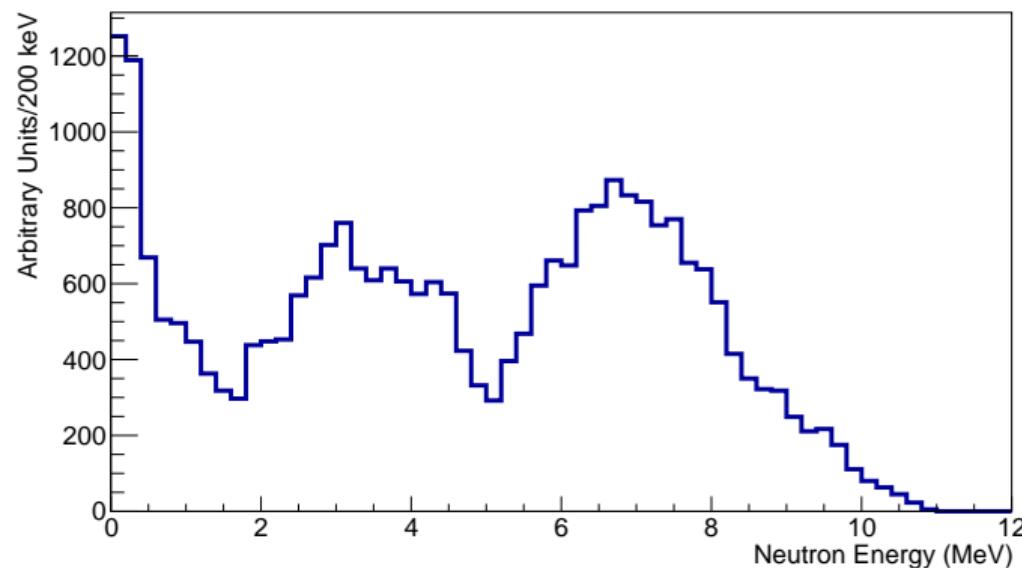
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- Geant4 has built in example in extended/hadronic/NeutronSource
- Simulates  $^{241}\text{Am}$   $\alpha$ -decay
- Lacks differential cross sections and crucial features



Geant4 extended/hadronic/NeutronSource example



# Implementation

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Aim: make the simulation as accurate as possible, efficient, open-source, complete

- Simulate  $n$  and  $^{12}\text{C}$  directly
  - High activity sources  $\Rightarrow 2.27 \times 10^6$  fast neutrons/s/Ci
  - Simulate one fast neutron per event vs one neutron every  $\approx 16300$  events using  $\alpha$  decay method
- Rejection sampling technique
- Integrated cross-section (1970) and Legendre polynomials for differentials (1975,1976 Geiger and Van Der Zwan) for fast neutron reaction



# Differential cross-section contribution

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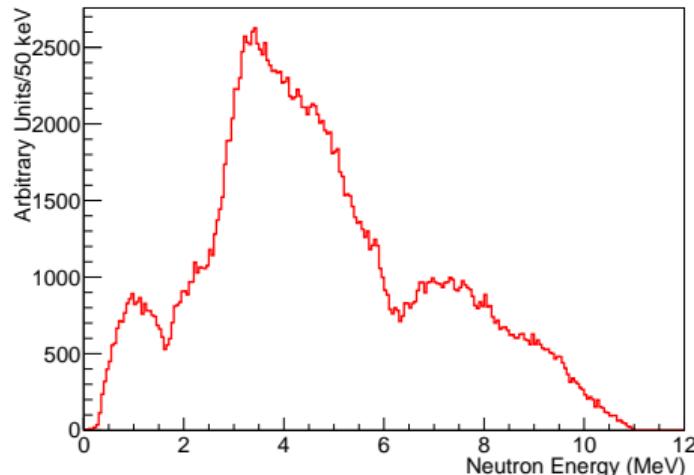
Theoretical Framework

Current Status

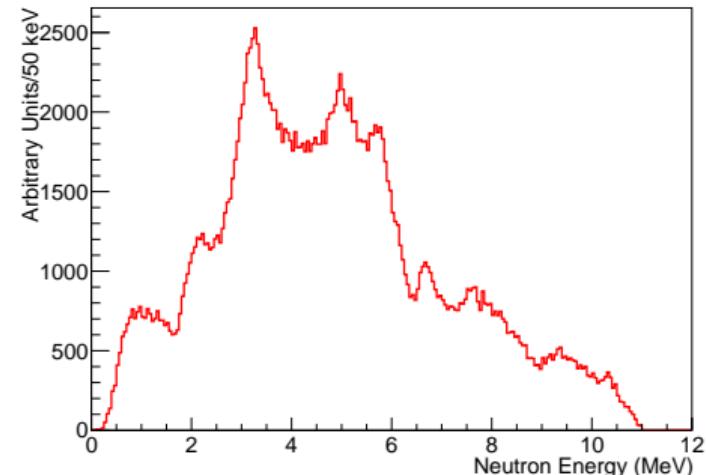
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Initial neutrons: without differential cross-sections model



Initial neutrons: with differential cross-sections model



# Disadvantages

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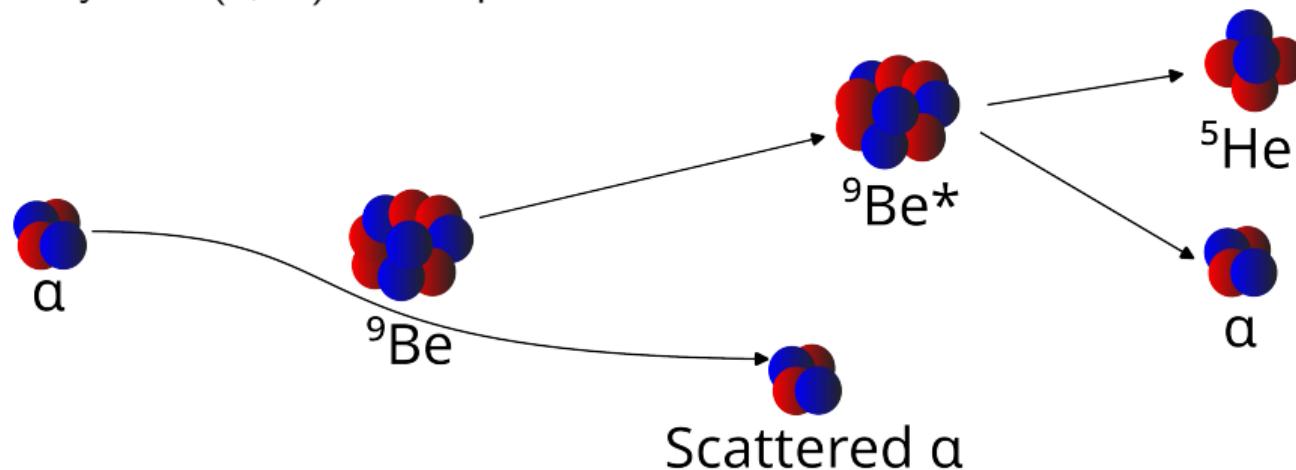
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Differential and Integrated cross section of beryllium-9 break-up not available

- ${}^9\text{Be}(\alpha, \alpha')$  scattering
- ${}^9\text{Be}^*$  angular decay information
- Other break-up channels more suppressed at interaction energy (< 5 MeV)  
e.g.  ${}^9\text{Be}^* \rightarrow \alpha + {}^5\text{He}$

Only have  $(n, 2n)$  break-up reactions





# Simulation Results - Emerging Neutrons

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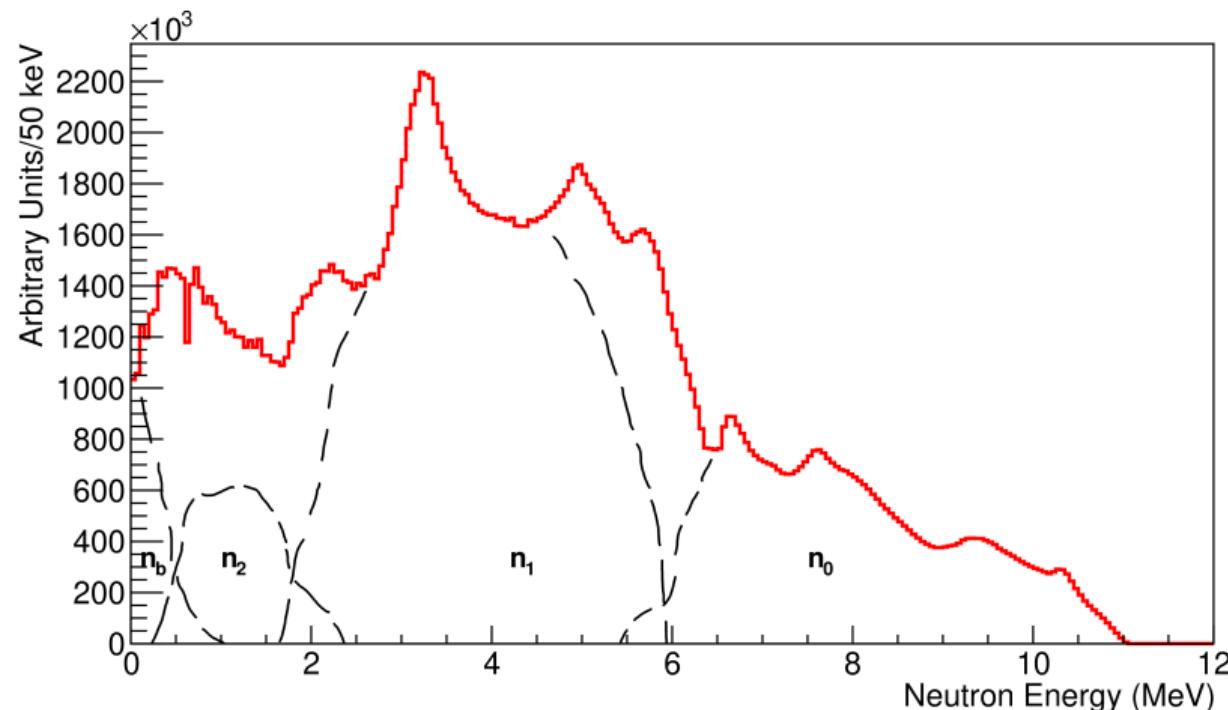
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Neutrons emerging from source casing (simulation)





# Simulation Results - Fission and Break-up Neutrons

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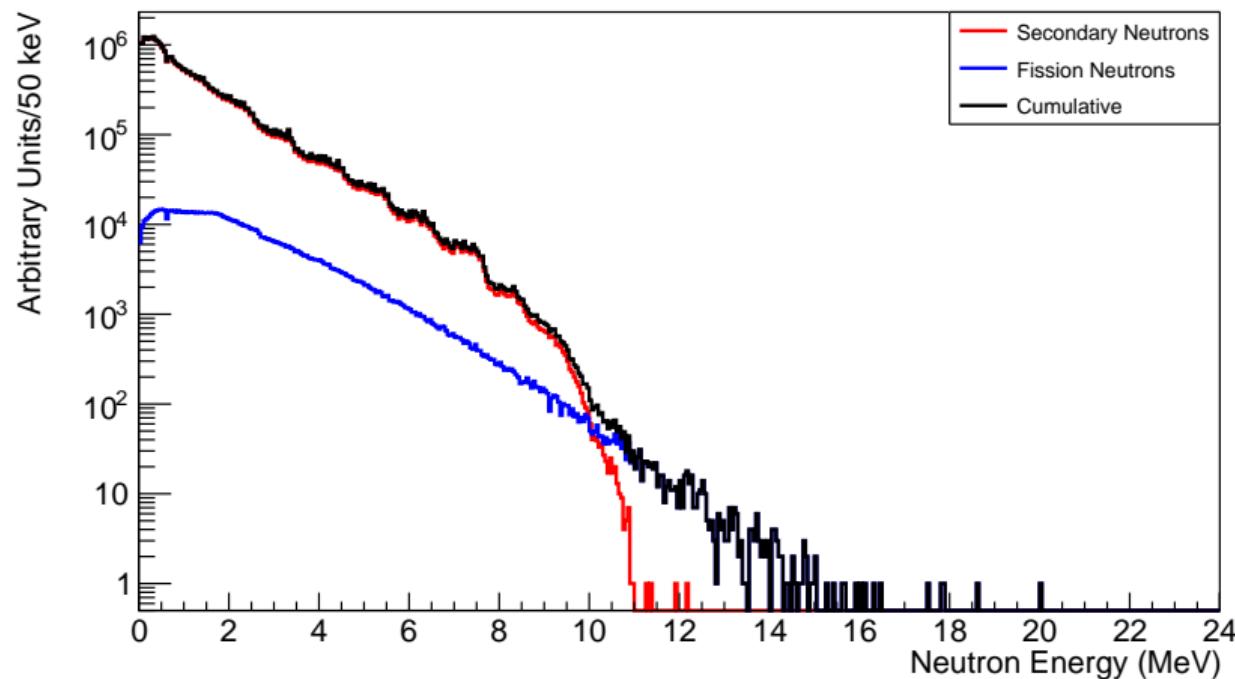
Current Status

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Conclusion

Fission and break-up neutrons emerging from the source material





# Simulation Results - AmBe carbon $\gamma$

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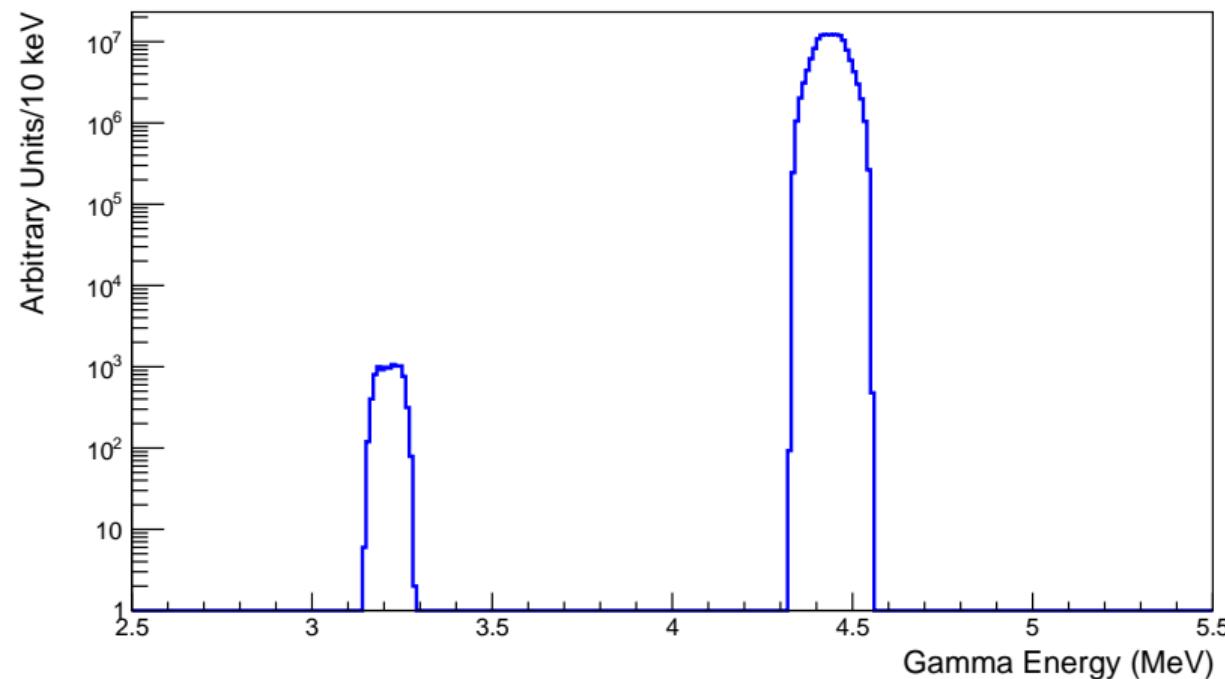
Current Status

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$26 : 10 : 64 = n_0 : n_1 : n_2$  as expected from cross section





# Model comparison

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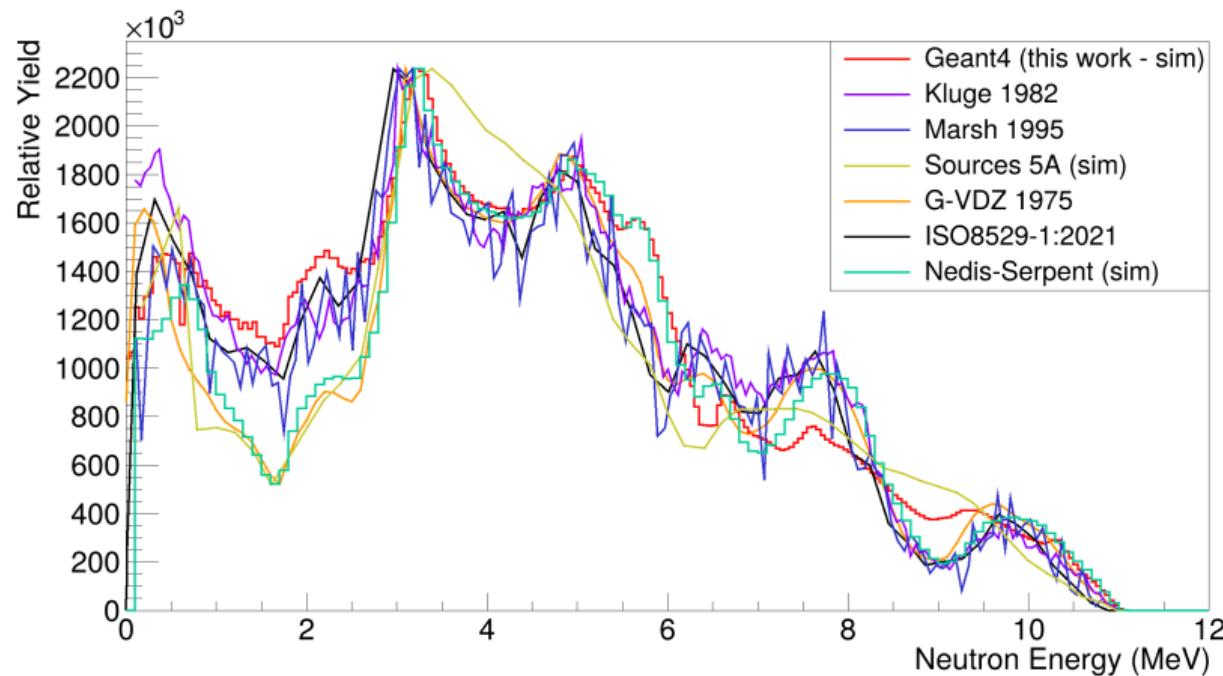
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## Comparison with AmBe standards





# Conclusion

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- Validated AmBe neutron spectrum in Geant4 - Open Source simulation available
- Correctly reproduced AmBe signature peaks
- Implemented 1970 and 1975-1976 Geiger-Van Der Zwan Cross sections (not otherwise present in Geant)
- Faster execution than full  $^{241}\text{Am}$   $\alpha$ -decay chain recreation
- Useful for analysis of flux, neutron moderation and dose in various media
- Future analysis of neutron moderation in water bath

Thank you for listening



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Backup Slides

## Backup Slides

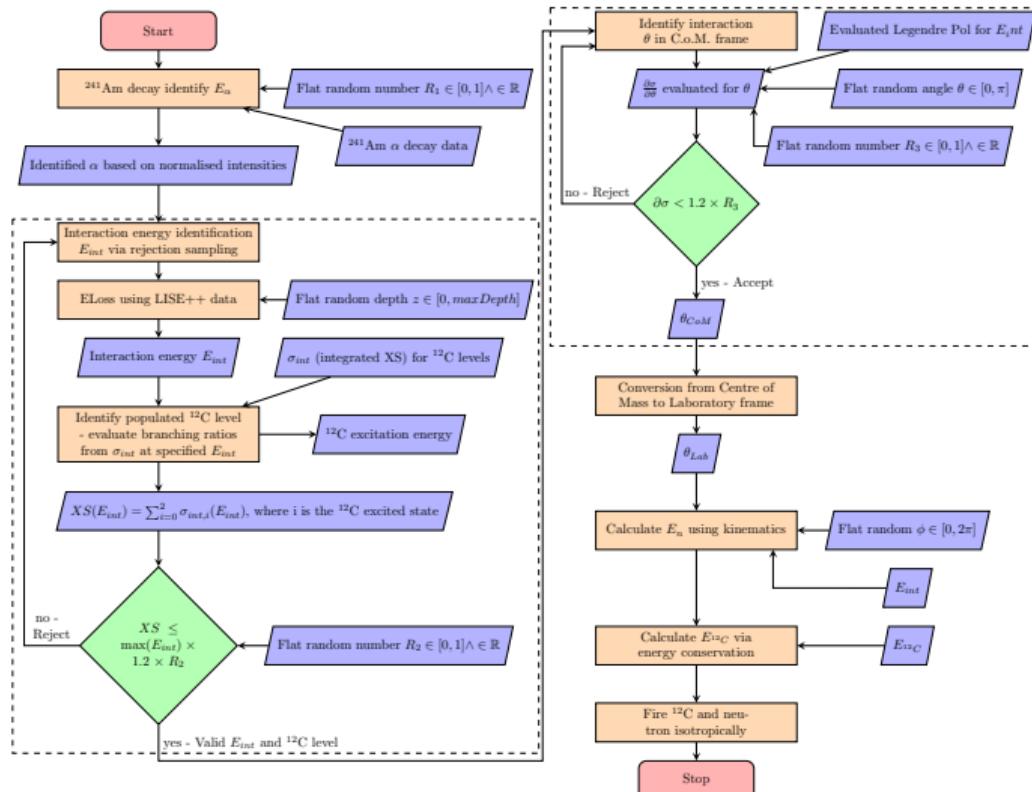


# Primary Generator flowchart

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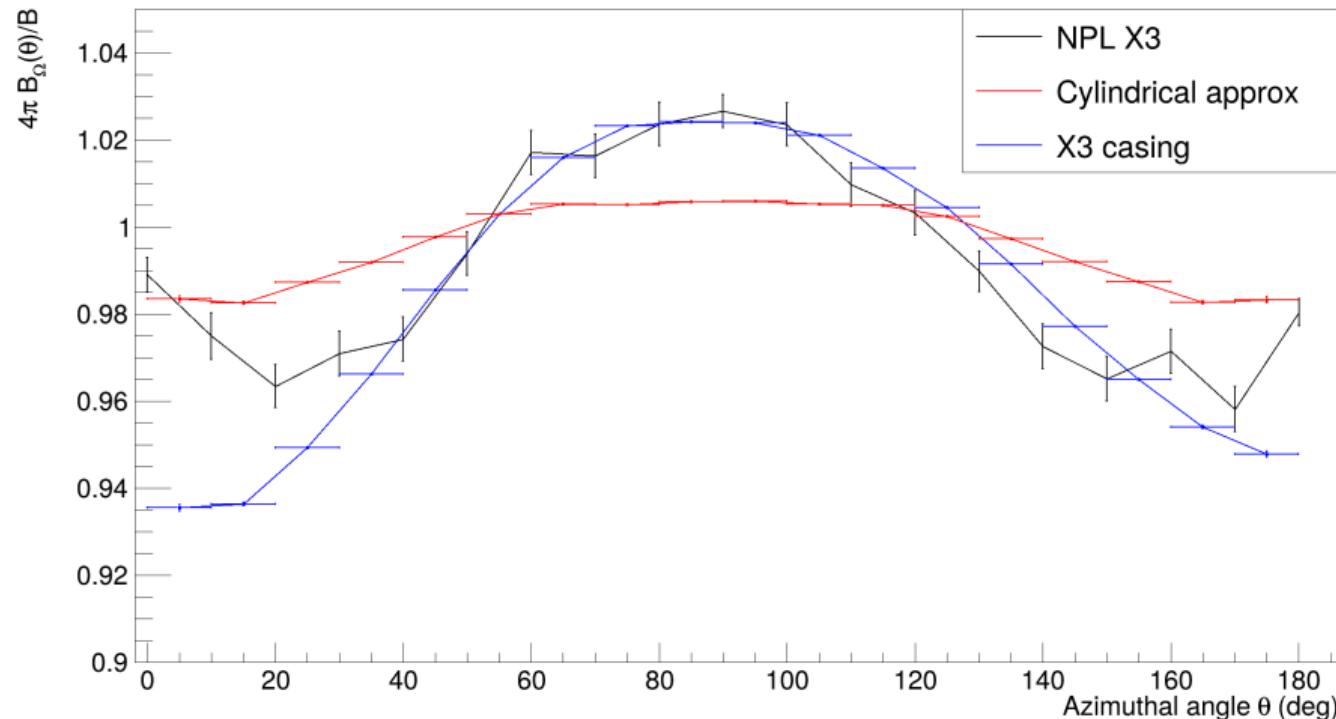


# Azimuthal emission

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# Investigation of water bath

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- Source neutron spectrum is known
- Source is at centre of 1 m tall, 1 m diameter water tank. The moderation profile is unknown

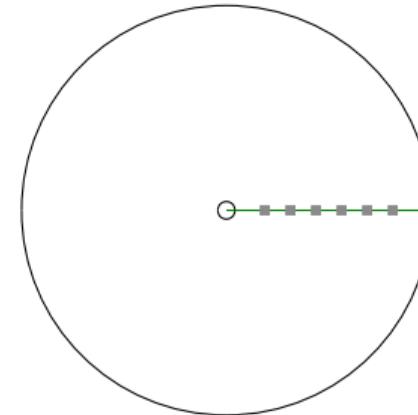


# Current analysis

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- Experimental  $\text{BF}_3$  and  ${}^3\text{He}$  flux to extrapolate neutron age and thermal diffusion length
- $\gamma$  spectrum from AmBe using hpGe for to verify production rate of fission products and dose rate

Measurements and analysis ongoing...



# Two group model

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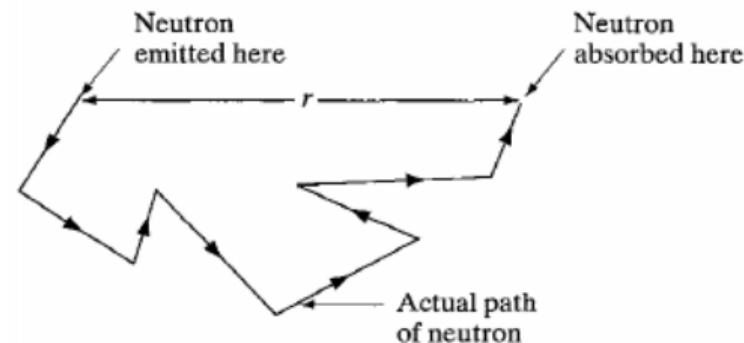
Does it actually agree with the two-group neutron moderation model?

Two group model:

$$\Phi_T = \frac{SL_T^2}{4\pi r D(L_T^2 - \tau_T)} (e^{-r/L_T} - e^{-r/\sqrt{\tau_T}})$$

describes thermal neutron diffusion and fast to thermal neutron moderation.

- $\tau_T \rightarrow$  (Fast) neutron age
- $L_t \rightarrow$  Thermal diffusion length



Neutron moderation  $L^2 = \frac{1}{6}r^2$   
[Lamarsh-Baratta 2001]



# Equivalent Dose - Preliminary

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Calculated dose for outgoing  $\gamma$  and neutrons from the water bath and verified against experimental

Sampling over 0.2 s spectrum

Particle	Experimental [ $\mu\text{Sv}/\text{h}$ ]	Simulated [ $\mu\text{Sv}/\text{h}$ ]
$\gamma$	1.54	8.05
n	0.8	1.68

Notes:

- Neutrons measured with Nuclear Enterprises NM-2 dose monitor ( $BF_3$ )
- Gammas measured with dose monitor calibrated in the 59-1332 keV range