



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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University of Birmingham, UK

26th November 2025 - Neutron User Club @ NPL



^{241}Am - ^9Be 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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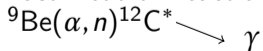
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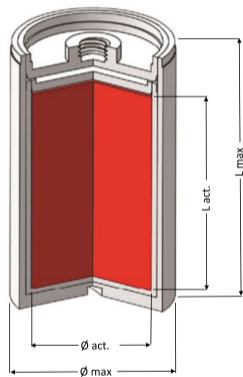
Mixture of AmO_2 and ^9Be powder — Stainless-steel
> 99% ^{241}Am
 ^{241}Am α emission:

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}C can be either in ground, 1st, 2nd (Hoyle) excited state



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



Reactions of interest

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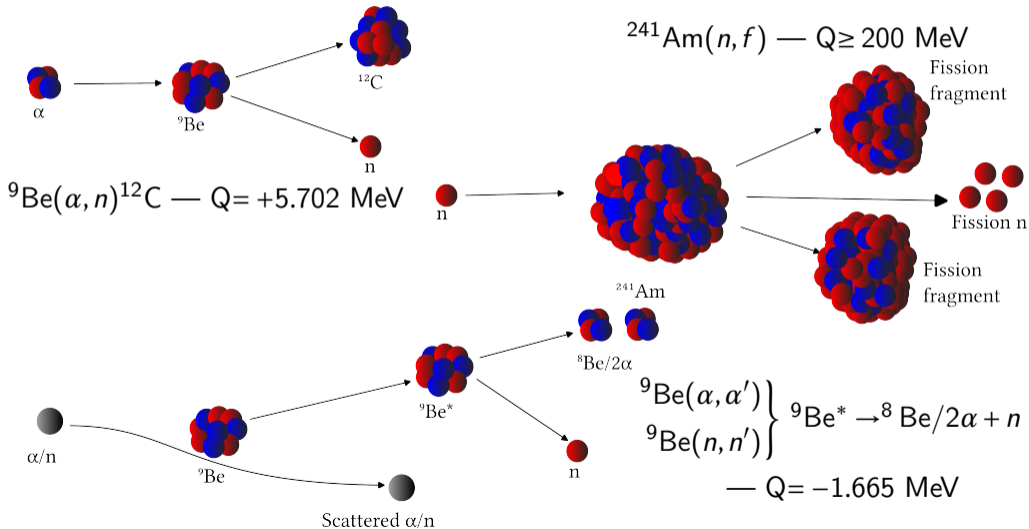
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Fast reaction

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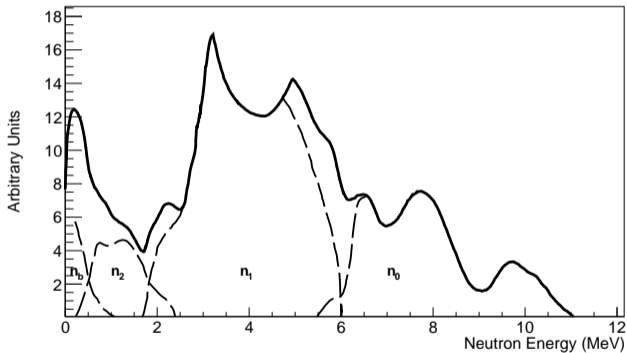
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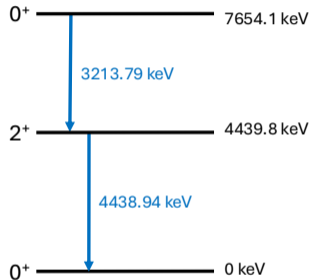
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AmBe neutron distribution per ^{12}C state [Geiger-Van Der Zwan 1975]



^{12}C

^{12}C states - ground, 1st,
2nd [NNDC]



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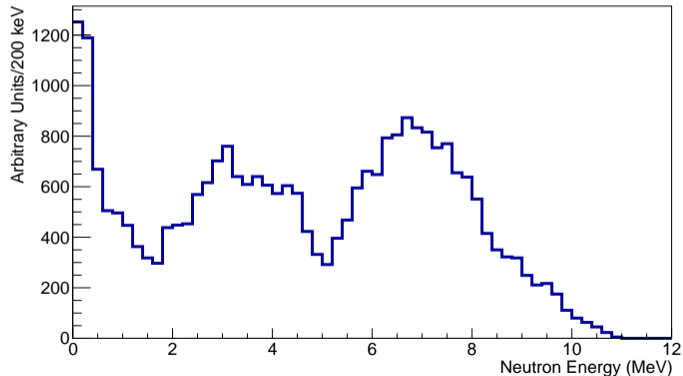
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- Geant4 has built in example in extended/hadronic/NeutronSource
- Simulates ^{241}Am α -decay
- Lacks differential cross sections and crucial features



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}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 ≈ 16300 events
using α 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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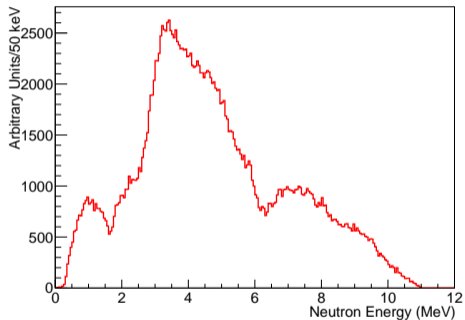
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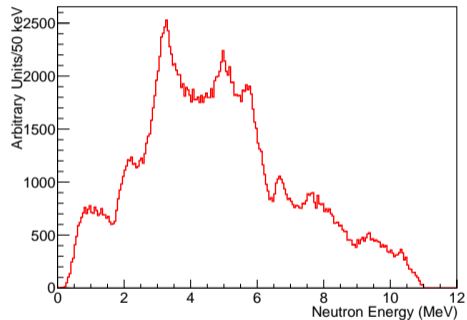
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Initial neutrons: without differential
cross-sections model



Initial neutrons: with differential
cross-sections model



Disadvantages

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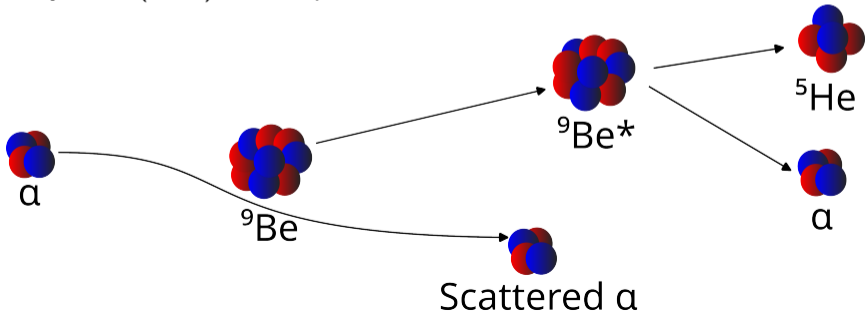
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Differential and Integrated cross section of beryllium-9 break-up not available

- ${}^9\text{Be}(\alpha, \alpha')$ 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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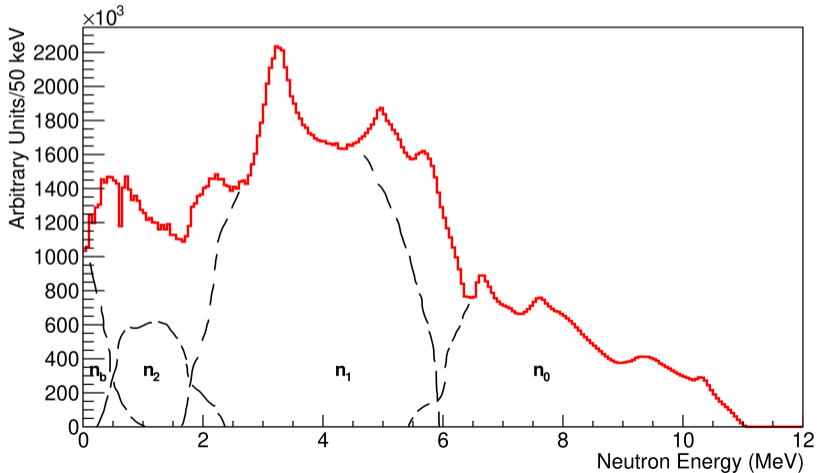
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Neutrons emerging from source casing (simulation)





Simulation Results - Fission and Break-up Neutrons

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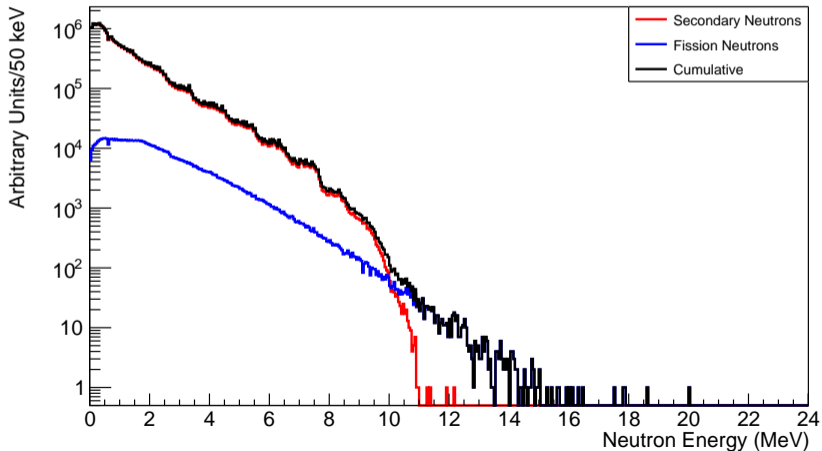
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Fission and break-up neutrons emerging from the source material





Simulation Results - AmBe carbon γ

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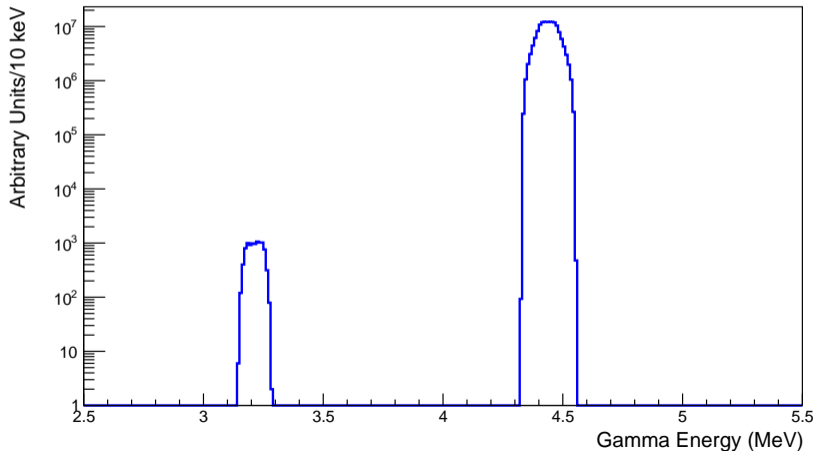
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$26 : 10 : 64 = n_0 : n_1 : n_2$ as expected from cross section





Model comparison

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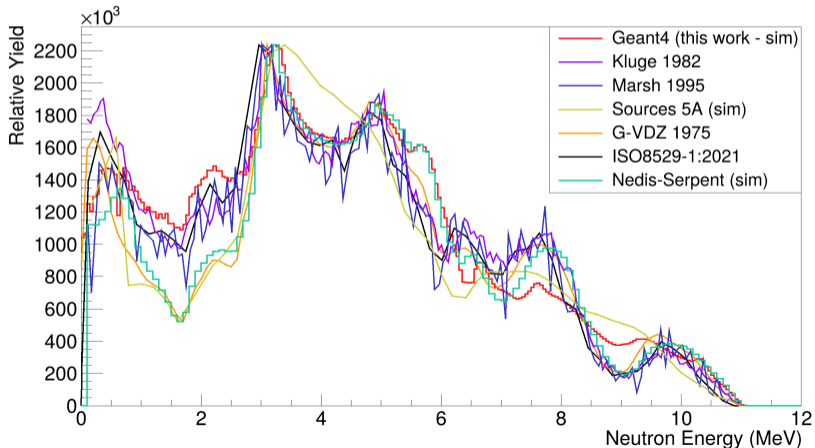
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Comparison with AmBe standards





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}Am α -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

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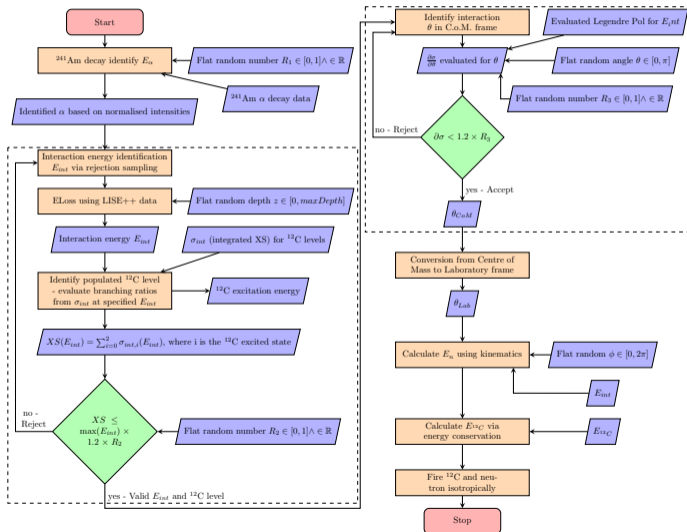


Primary Generator flowchart

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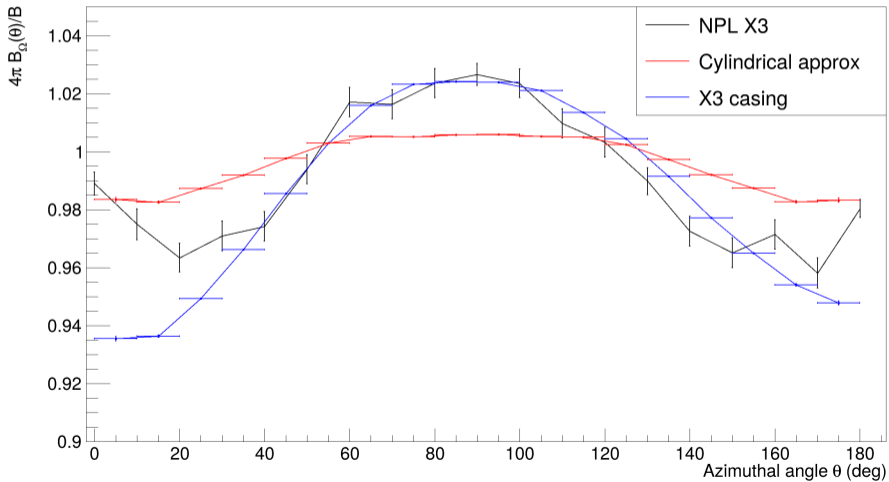


Azimuthal emission

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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

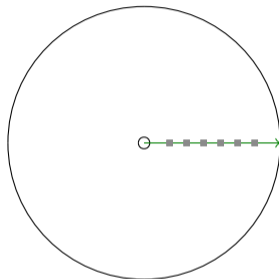


Current analysis

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- Experimental BF_3 and ^3He flux to extrapolate neutron age and thermal diffusion length
- γ 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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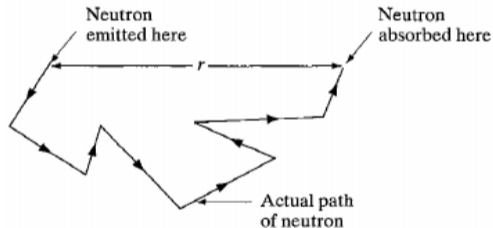
Does it actually agree with the two-group neutron moderation model?

Two group model:

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

describes thermal neutron diffusion and fast to thermal neutron moderation.

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



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



Equivalent Dose - Preliminary

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Calculated dose for outgoing γ and neutrons from the water bath and verified against experimental

Sampling over 0.2 s spectrum

Particle	Experimental [$\mu\text{Sv/h}$]	Simulated [$\mu\text{Sv/h}$]
γ	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