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

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^{241}Am-^{9}Be Neutron source

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 $^{1}\mathrm{H}(n,\gamma)^{2}\mathrm{H}$)

Reaction of Interest

Mixture of AmO_2 and ^{9}Be powder — Stainless-steel

$> 99\%$ ^{241}Am

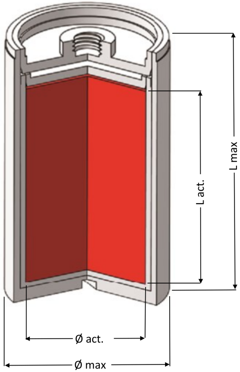
^{241}Am α emission:

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

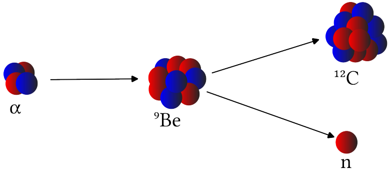
$^{9}\mathrm{Be}(\alpha, n)^{12}\mathrm{C}^{*} \rightarrow \gamma$

^{12}C can be either in ground, 1st, 2nd (Hoyle) excited state



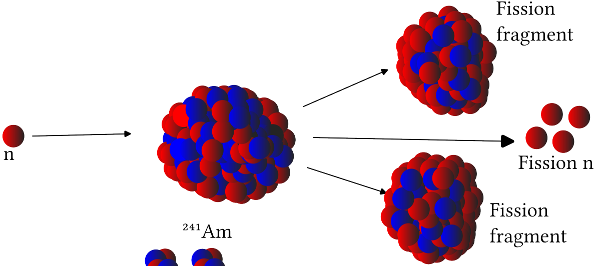
Source drawing, AmBe mixture (red) encased in steel [Raims Ltd]

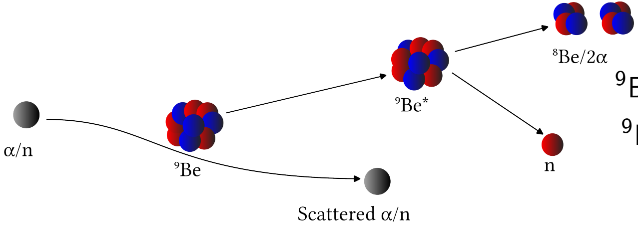
Reactions of interest



$^{9}\text{Be}(\alpha,n)^{12}\text{C}$ — Q= +5.702 MeV

$^{241}\text{Am}(n,f)$ — Q≥ 200 MeV

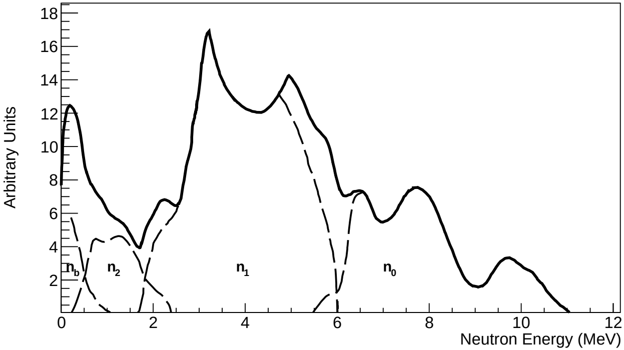




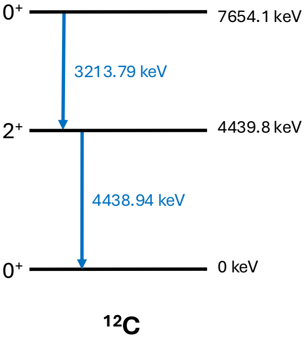
$$\left.\begin{array}{r} ^{9}\text{Be}(\alpha,\alpha') \\ ^{9}\text{Be}(n,n') \end{array}\right\} \; ^{9}\text{Be}^{*} \rightarrow {}^{8}\text{Be}/2\alpha + n$$

— Q= −1.665 MeV

Fast reaction



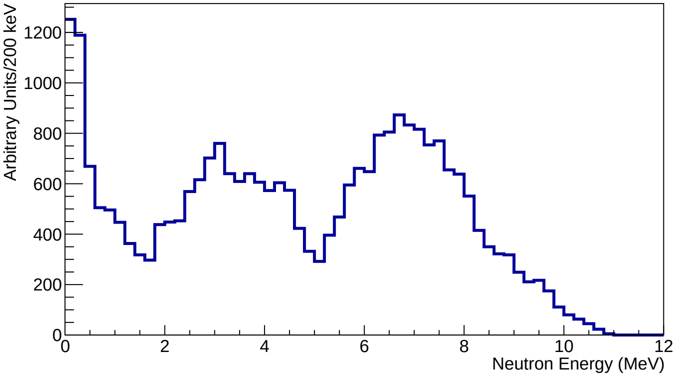
AmBe neutron distribution per ^{12}C state [Geiger-Van Der Zwan 1975]



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

Current status

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



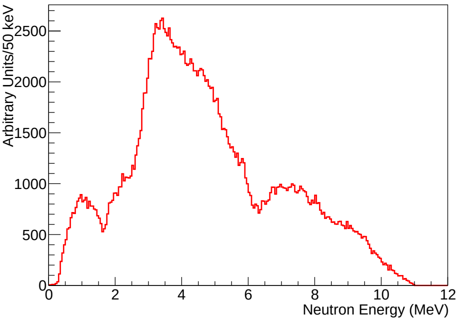
Geant4 extended/hadronic/NeutronSource example

Implementation

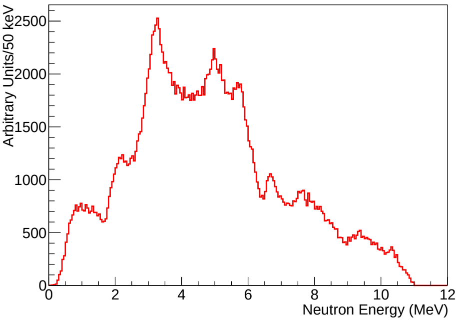
Aim: make the simulation as accurate as possible, efficient, open-source, complete

- 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 $\approx$ 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



Initial neutrons: without differential cross-sections model



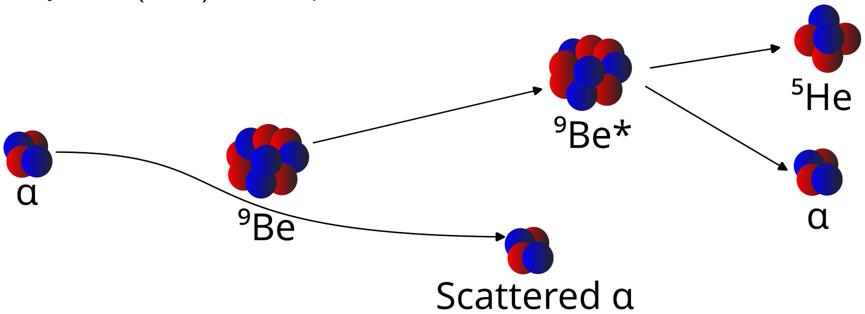
Initial neutrons: with differential cross-sections model

Disadvantages

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

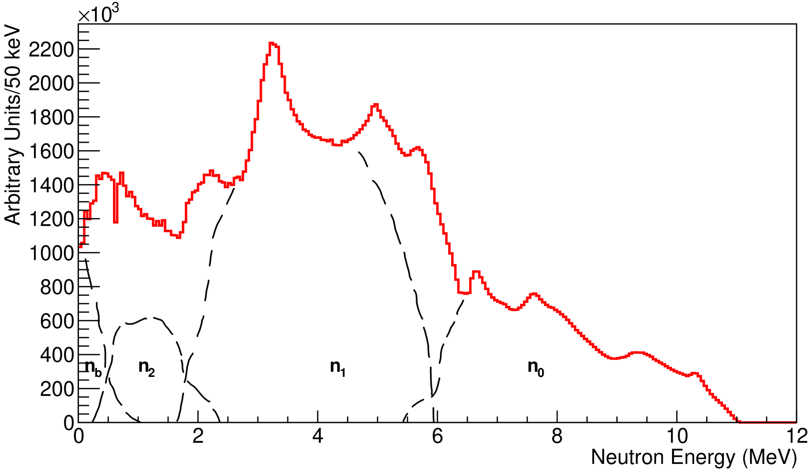
- $^{9}\mathrm{Be}(\alpha,\alpha')$ scattering
- $^{9}\mathrm{Be}^{*}$ angular decay information
- Other break-up channels more suppressed at interaction energy (<5 MeV) e.g. $^{9}\mathrm{Be}^{*} \rightarrow \alpha + ^{5}\mathrm{He}$

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



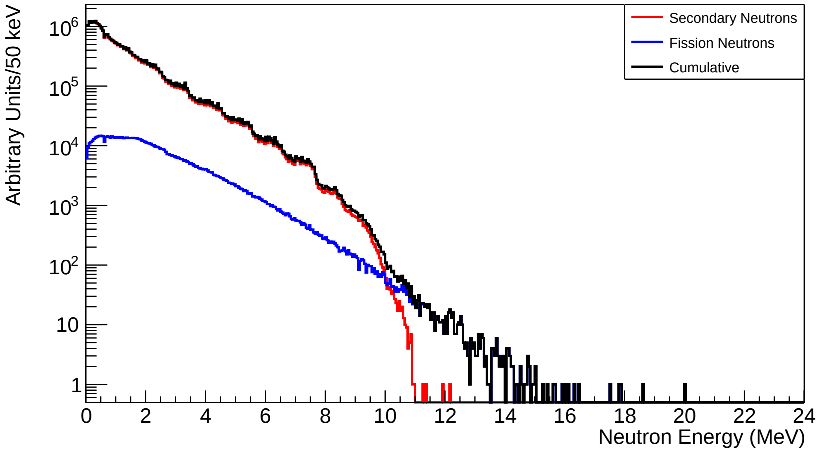
Simulation Results - Emerging Neutrons

Neutrons emerging from source casing (simulation)



Simulation Results - Fission and Break-up Neutrons

Fission and break-up neutrons emerging from the source material



Simulation Results - AmBe carbon γ

AmBeSim

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Theoretical Framework

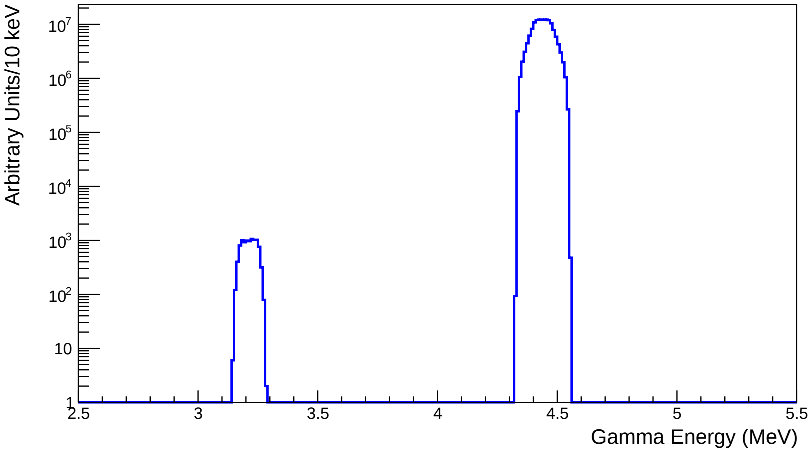
Current Status

Primary Generator

Emerging Neutrons

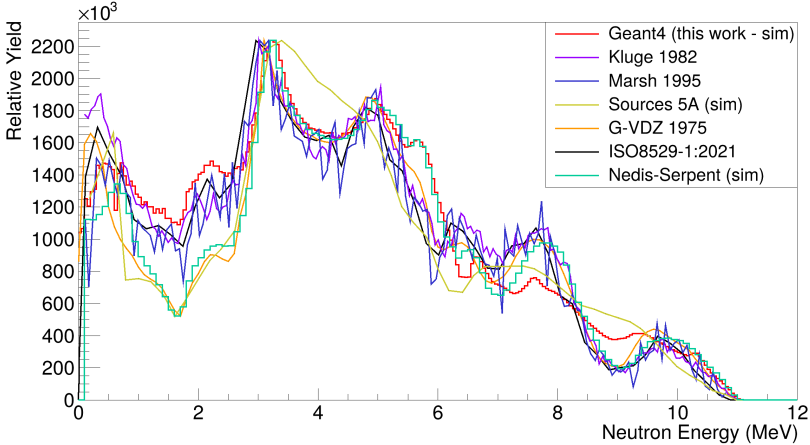
Conclusion

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



Model comparison

Comparison with AmBe standards



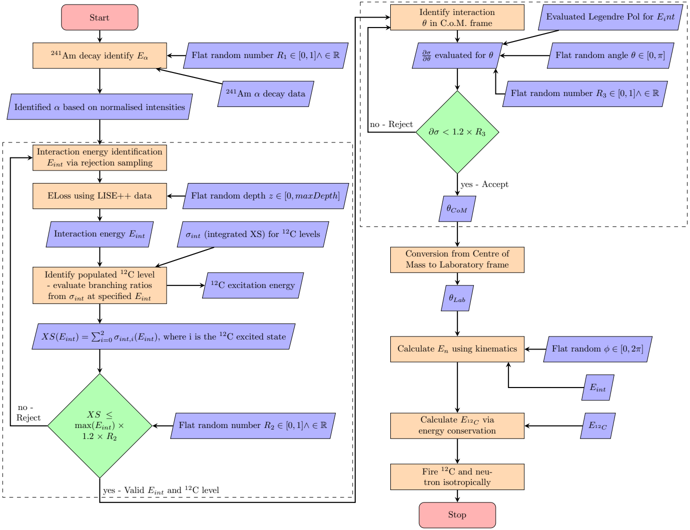
Conclusion

- 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

Backup Slides

Primary Generator flowchart



Azimuthal emission

AmBeSim

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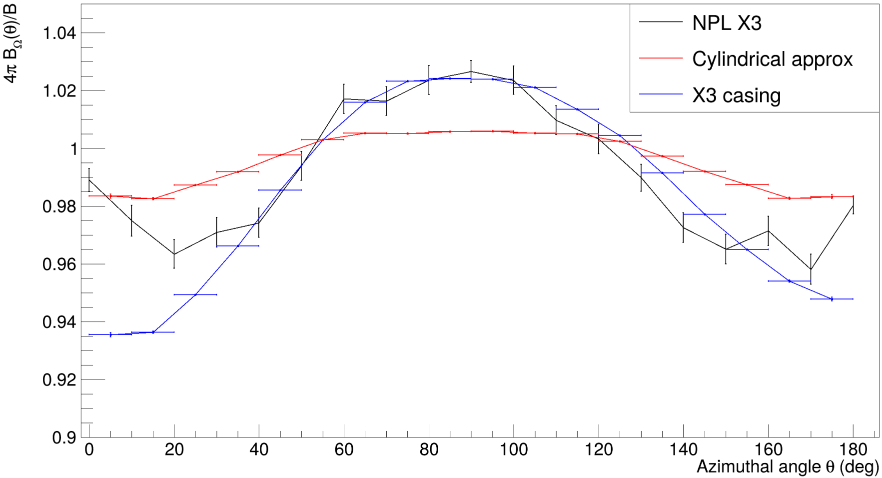
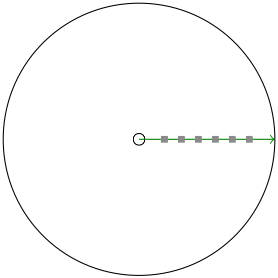
Backup Slides



Investigation of water bath

- 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



- 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

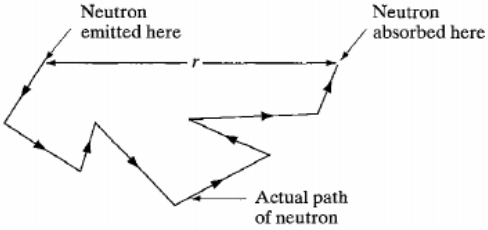
Does it actually agree with the two-group neutron moderation model?

Two group model:

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

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

Calculated dose for outgoing γ and neutrons from the water bath and verified against experimental
Sampling over 0.2 s spectrum

Particle	Experimental [μSv/h]	Simulated [μSv/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