Simulation of a $^{241}Am-^{9}Be$ neutron source and its moderation using Geant4

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Introduction

AmBe neutron source in water tank.
Fast neutrons are moderated by water. Used for

- Mimic neutron moderation in a nuclear reactor
- Neutron activate samples for undergraduate forensic experiments

But how effective is the moderation?

Reaction of Interest

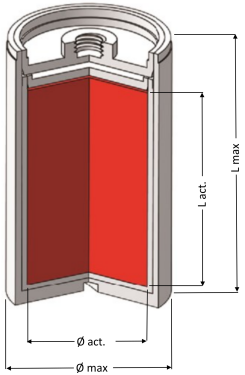
Mixture of AmO_2 and ^9Be powder. $> 99\%$ ^{241}Am
Stainless-steel casing
^{241}Am is α emitter:

- 5.4856 MeV at 84.8% intensity
- 5.4428 MeV at 13.1% intensity
- 5.388 MeV at 1.660% intensity

Fast Neutron reaction:

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

Q value: 5.702 MeV
^{12}C can be either in ground, first, or second excited



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

^{12}C states in AmBe

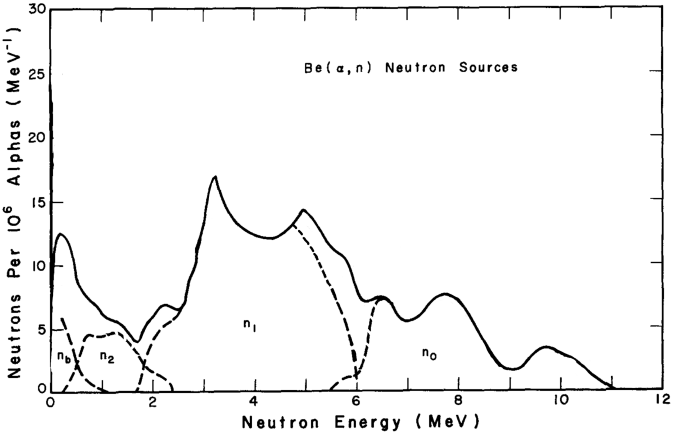


Figure: AmBe neutron distribution per ^{12}C state [Geiger-Van Der Zwan 1975]

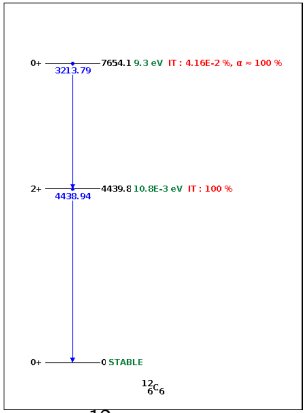


Figure: ^{12}C states - ground, 1st, 2nd [NNDC]

Thermal Spectrum

From break-up reactions in ^{9}Be

$$^{9}\mathrm{Be}(\alpha,\alpha')^{9}\mathrm{Be} \rightarrow ^{8}\mathrm{Be} + n$$

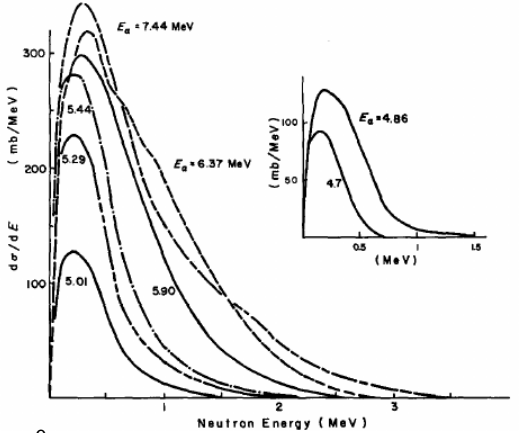


Figure: ^{9}Be break-up neutrons spectrum [Geiger-Van Der Zwan 1975]

Fission neutrons

$^{241}\mathrm{Am}(n,f)$ products give additional energy tail, from thermal up to ≈ 18 MeV

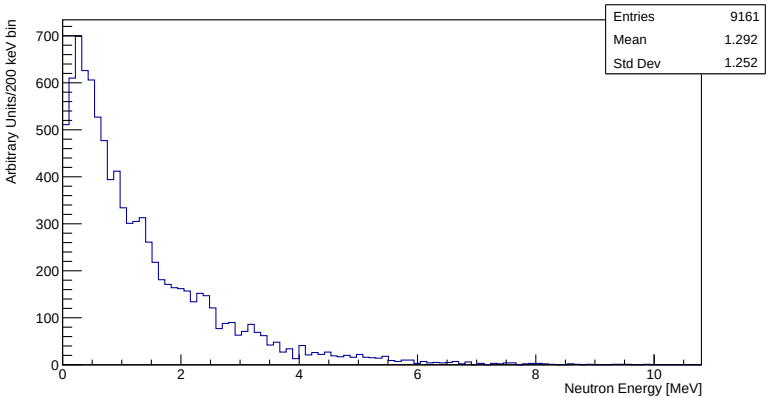


Figure: Secondary neutrons from ^{9}Be break-up and fission products (high energy)

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

Two group model

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

Two group model:

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

describes thermal neutron difusion and fast to thermal neutron moderation.

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

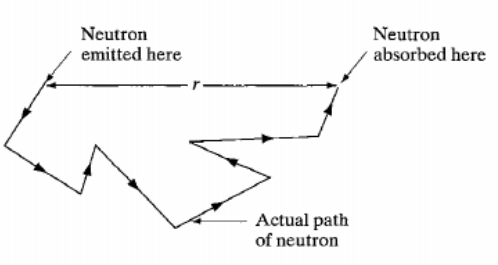


Figure: Neutron moderation $L^2 = \frac{1}{6}\overline{r^2}$ [Lamarsh-Baratta 2001]

Geant4 isotropic assumption

- Geant4 has built in example in extended/hadronic/NeutronSource
- It assumes Isotropic reaction - does not account for differential cross section

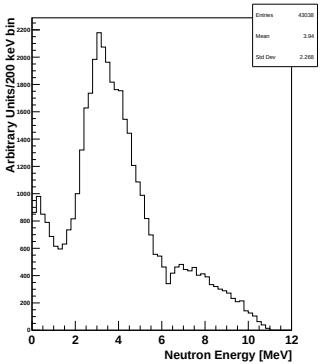


Figure: Geant4 extended/hadronic/NeutronSource example

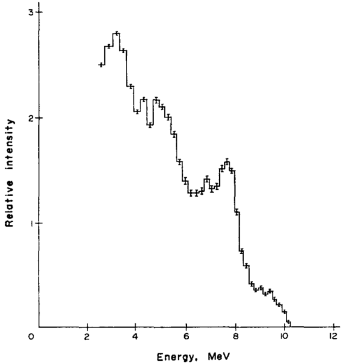


Figure: Experimental spectrum [Lorch 1973]

Geant4 isotropic assumption

- Geant4 has built in example in extended/hadronic/NeutronSource
- It assumes Isotropic reaction - does not account for differential cross section

Figure: It's actually pretty bad [Meme]

Differential cross-section contribution

Anisotropic approach first suggested in 1963 by Anderson and Bond
Our model:

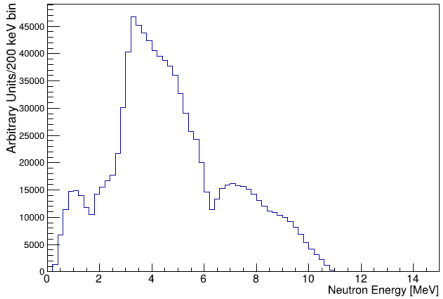


Figure: Initial neutrons: isotropic model

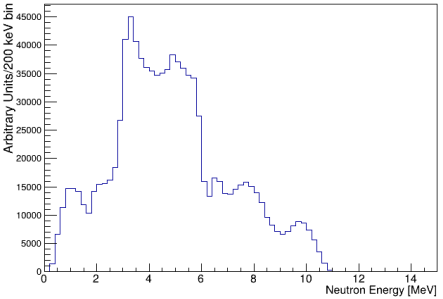


Figure: Initial neutrons: anisotropic model

AmBe model in Geant4

Bert HPT Physics class for high precision neutrons down to thermal energies
Generated 1s of fast neutrons: 2.27×10^6 fast neutrons/1Ci/s

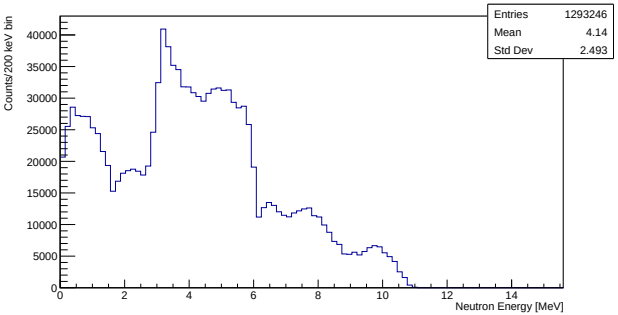


Figure: AmBe spectrum with fission fragments

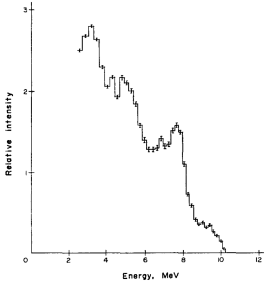


Figure: Experimental spectrum [Lorch 1973]

Structure matches, intensities differ because of acquisition techniques

Neutron spectrum

- AmBe Fast neutron spectrum verified
- ^{9}Be break-up neutrons need to be implemented anisotropically
- Production rate of fission products to be verified

γ spectrum

Produced γ - Geant4 scoring

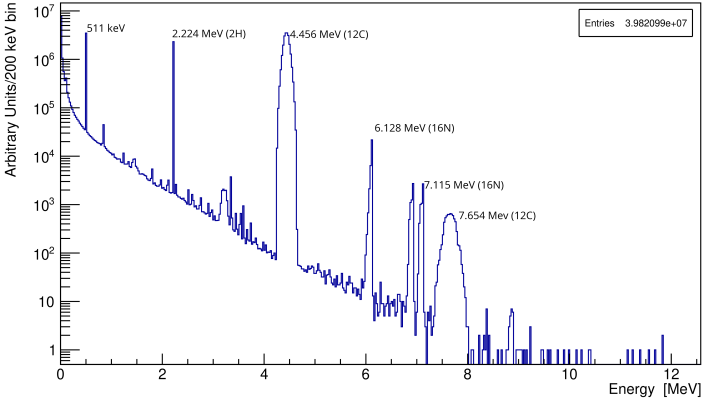


Figure: Gammas from AmBe water bath

Equivalent Dose - Preliminary

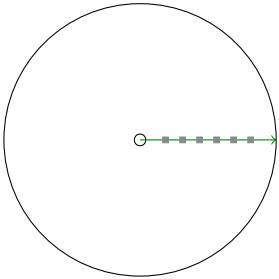
Calculated dose for outgoing γ and neutrons from the water bath and verified against experimental
Sampling over 0.2 s spectrum

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

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 ongoing...

Summary

- Validated AmBe neutron spectrum in Geant4
- Secondary γ compatible with expected ones
- Dose analysis WIP
- Two-group analysis WIP

Thank you for listening