^{9}Li/^{8}He **generator**

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Abstract

This note describes the Monte Carlo generator for ^{9}Li/^{8}He .

1 Introduction

Cosmogenic isotopes ^{9}Li and ^{8}He are the most problematic backgrounds in the reactor neutrino expertiments due to their long life-times (0.18 s and 0.12 s, respectively) and possible β-neutron emission. The β-neutron emission gives the prompt signal (the β) and delayed signal (neutron capture), which makes it indistinguishable from inverse beta decay. The branching fractions of β-neutron cascade decays for ^{9}Li and ^{8}He are 49.5% and 16$\pm$1%, respectively.

Ry Ely, Jen-Chieh Peng and Viktor Pec have done many work [4, 5] on developing ^{9}Li/^{8}He generator.

This work's neutron and α spectra are mainly based on the following reference [1, 2, 3], they deserve careful attention if you plan to improve the model.

2 ^{9}Li/^{8}He decay

The decay scheme for ^{9}Li/^{8}He has been studied in [1, 2, 3] and the results are summerized in Table 1.

The goal for ^{9}Li/^{8}He generator is to correlate the β, neutron and α spectra as much as possible.

3 β spectrum

We produce the β spectrum from Fermi theory. The unnormalized β spectrum is given by

$$\sqrt{E^2 + 2m_e E}(E + m_e)(Q - E)^2 F(Z, E), \tag{1}$$

where E is the energy of the electron, m_e is the electron mass, Q is the total decay energy, Z is the atomic number, and $F(Z, E)$ is the fermi function. The fermi function is same as the one used in GenDecay, which is taken from Geant4. We used Breit-Wigner functions for the broad intermediate states, with mean and width shown in Table 1.

Mother	Inter-state	Width(MeV)	BR(%)	α	β	γ	neutron
^{9}Li	^{9}Be(ground)	0	49.2		$\clubsuit$		
^{9}Li	^{9}Be(2.43 MeV)	0.00077	29.7	$\clubsuit$	$\clubsuit$		$\clubsuit$
^{9}Li	^{9}Be(2.78 MeV)	1.08	15.8	$\clubsuit$	$\clubsuit$		$\clubsuit$
^{9}Li	^{9}Be(7.94 MeV)	1.0	1.5	$\clubsuit$	$\clubsuit$		$\clubsuit$
^{9}Li	^{9}Be(11.28 MeV)	0.575	1.1	$\clubsuit$	$\clubsuit$		$\clubsuit$
^{9}Li	^{9}Be(11.81 MeV)	0.40	2.7	$\clubsuit$	$\clubsuit$		$\clubsuit$
^{8}He	^{8}Li(0.98 MeV)	0	84		$\clubsuit$	$\clubsuit$	
^{8}He	^{8}Li(3.21 MeV)	1.0	12		$\clubsuit$	$\clubsuit$	$\clubsuit$
^{8}He	^{8}Li(5.4 MeV)	0.65	4		$\clubsuit$	$\clubsuit$	$\clubsuit$

Table 1: ^{9}Li/^{8}He decay scheme, $\clubsuit$ means the associated particle is considered in the generator.

The β spectra for different intermediate states are shown in Fig. 1, which is just a illumination of how the spectra look like without any renormalization. Fig. 2 shows the β spectra with all the channels renormalized according their branching fractions. Not all the β decays have delayed neutrons, the spectra for β decays followed by neutron emission are shown in Fig 3.

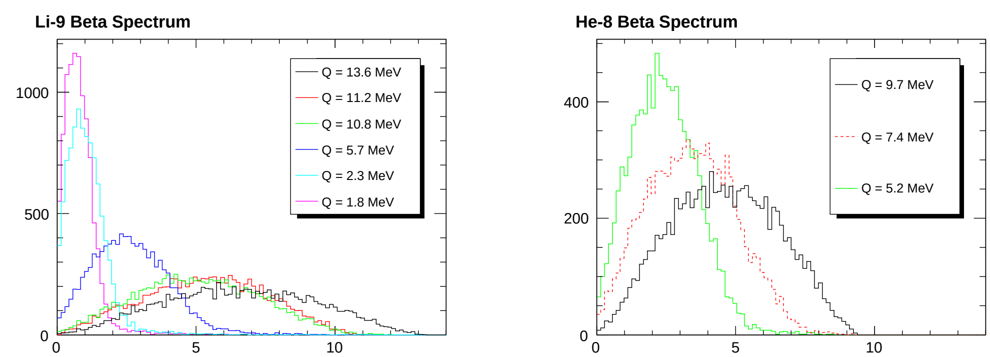

Figure 1: ^{9}Li/^{8}He β spectrum for different energy levels, note here the spectrum hasn't been normalized to respect the branching fractions.

4 ^{9}Li neutron and α spectra

While the determinatin of β spectrum is relatively easy due to Fermi theory, it is much harder to get neutron and α spectra, since a complete parameterization is complicate and hard to implement.

Let's take a look at the ^{9}Li neutron spectrum in Fig. 4. [1] says the 682 keV peak is due to process: ^{9}Be*(2.43 MeV)$\rightarrow$^{5}He+α, ^{5}He$\rightarrow$ $n+\alpha$. The lower peak is mainly contributed by ^{9}Be*(2.43 MeV)$\rightarrow$^{8}Be(2^{+})+n, ^{8}Be(2^{+})$\rightarrow$ α+α, and the higher bump is mainly from ^{9}Be*(2.78 MeV) $\rightarrow \alpha+\alpha+n$. Without knowing the complicate parameterization procedure, we fit the spectrum with 3 Breit-Wigner functions, roughly resemble the above three cases. The fit result is

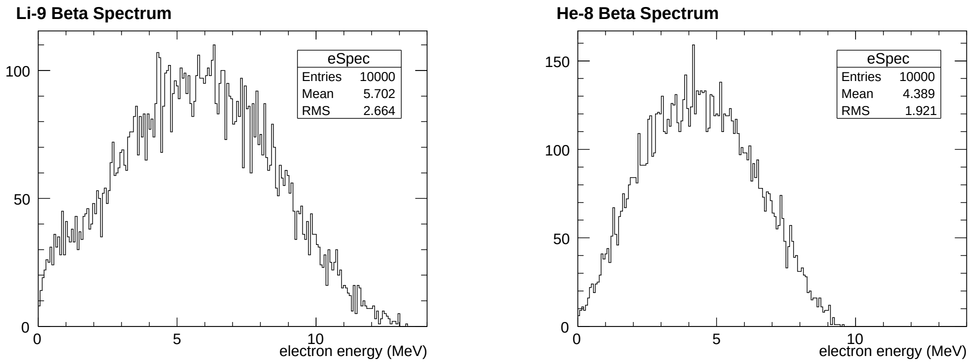

Figure 2: ^{9}Li/^{8}He β spectra for all decay channels

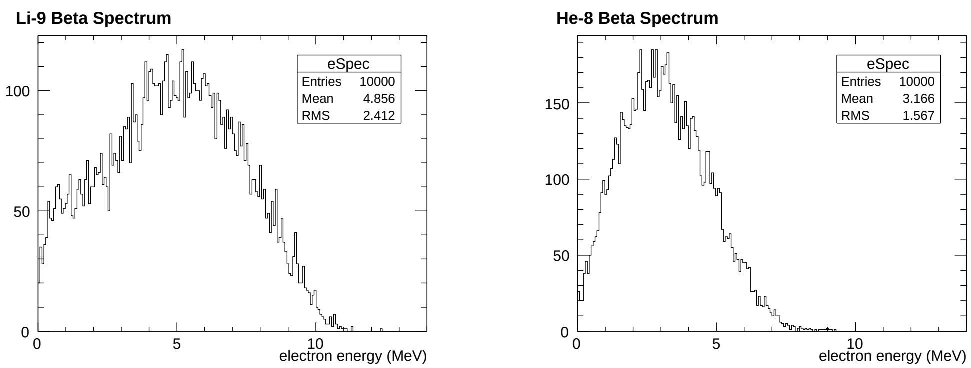

Figure 3: ^{9}Li/^{8}He β spectra for only the channels with neutrons

shown in the right plot of Fig. 4. The contributions from higher excitation levels are essentially constant or slightly decreasing towards the low energy end of the spectrum. We apply a Breit-wigner function with mean=0.8 MeV and width=1.5 MeV (these values are chosen based on data spectrum) to represent the higher energy excitation levels.

The α spectrum is shown in Fig. 5, which has a high energy tail. The inset shows a fit taking the 11.28 MeV and 11.81 MeV states into account, the agreement between data and fit confirms the existance of high energy intermediate states. We integrate from the high side of Fig. 5 until it reaches 10.4% of the toal spectrum. We associate the high energy states wiht this part of α particles. The 2.43 MeV and 2.78 MeV states are associated with the rest 89.6% α particles. Note that α particles are always shown in pairs, their energy is sampled from the same spectrum.

The β, neutron and α spectra for ^{9}Be(2.43 MeV), ^{9}Be(2.78 MeV) and ^{9}Be(7.94 MeV, 11.28 MeV, 11.81 MeV) intermediate states are shown in the first, second and third row of Fig. 6, respectively.

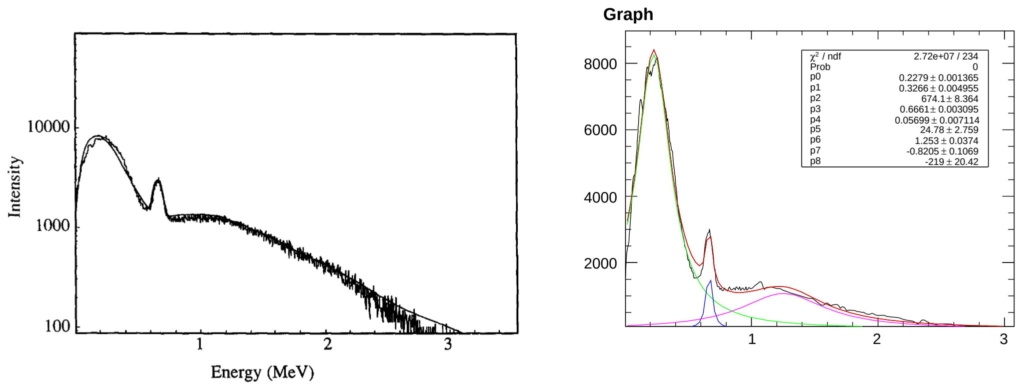

Figure 4: ^{9}Li neutron spectrum. The left plot is from [1], the right plot is fitting the data with 3 Breit-Wigner functions.

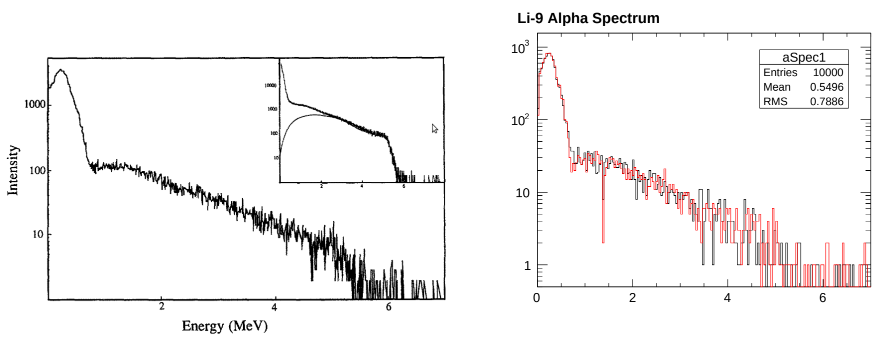

Figure 5: ^{9}Li α spectrum. The left plot is from [1], the right plot is generated α spectra. Note that there are two α's in the right plot, they have same distribution.

5 ^{8}He neutron spectrum

The experimental and calculated nuetron spectrum from ^{8}He is shown in Fig. 7 [2]. There are two states fitted in the distribution. The dot-dashed curve is from the 1 MeV broad 3.21 MeV state and the dashed curve is from the 5.4 MeV state. The arrows indicate the normalization points. The insert shows the difference between the fit and data. The calculated spectrum can't explain the data at the lowest energy and at about 1.8 MeV.

Several years later, F.C. Barker *et al.* [3] fitted the data again using R-matrix formula. The result is shown in Fig. 8. The agreement between data and fit results becomes better. Their results show that the branching fraction of ^{8}He to 3.21 MeV state is about 3 times of that to 5.4 MeV state.

Though there are many ambiguities in the details of the decay, the following facts are solid.

- 84% ^{8}He decay to the 981 keV first excited state in ^{8}Li, then release a photon with 981 keV energy.
- 16% ^{8}He decay to final states with neutrons.
- Among the 16% decays, 32% emits a photon with 478 keV energy.

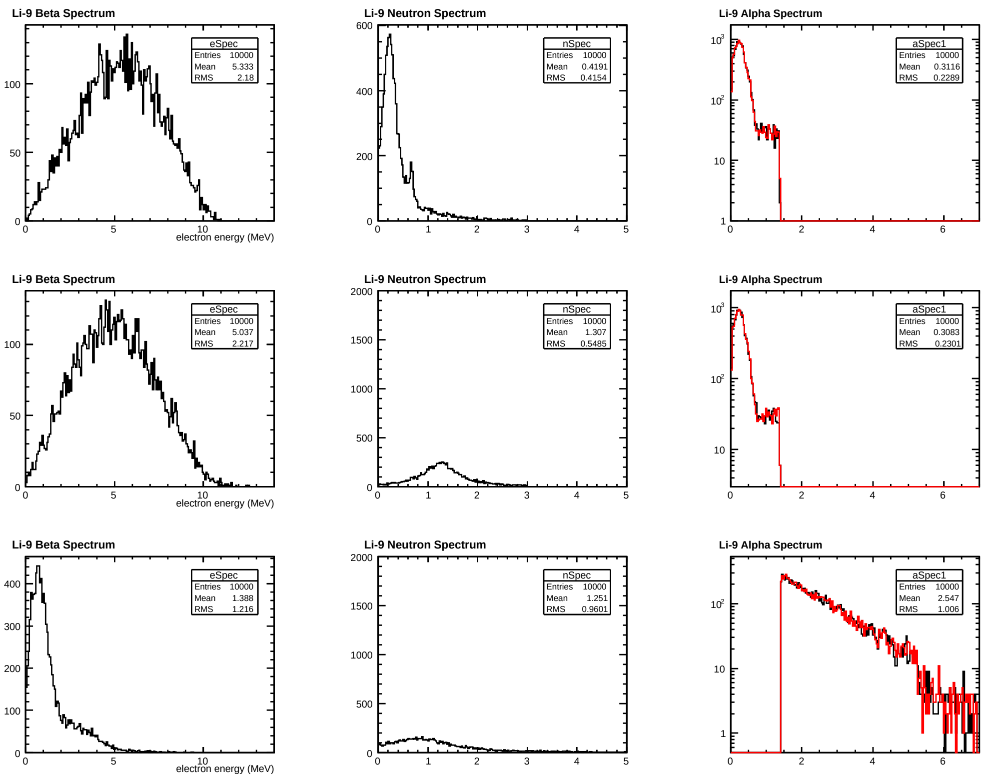

Figure 6: ^{9}Li β, neutron and α spectra correlation. The first row is for ^{9}Be(2.43 MeV) intermediate state, the second row is for ^{9}Be(2.78 MeV) intermediate state, the third row is for ^{9}Be(7.94 MeV, 11.28 MeV, 11.81 MeV) intermediate states.

In our generator, we generate the neutron spectrum of ^{8}He according the data spectrum without any effort to parameterize the intermediate states (the right plot in Fig. 7). We only make sure the branching fractions for all the particles are correct. Photons are considered in the decays with the right amount. The correlation between β spectrum and neutron spectrum is not considered. α spectrum is not considered.

Clearly there is difference between our model and real ^{8}He decay (no α's, no correlation between β and neutron spectra), however, results from KamLand show that more than 80% of the ^{9}Li/^{8}He isotopes from cosmic muons are ^{9}Li . And since only 16% of ^{8}He emits neutrons, the effect of the defection in ^{8}He generator may turns out not important. However, this needs more detailed simulation study to check.

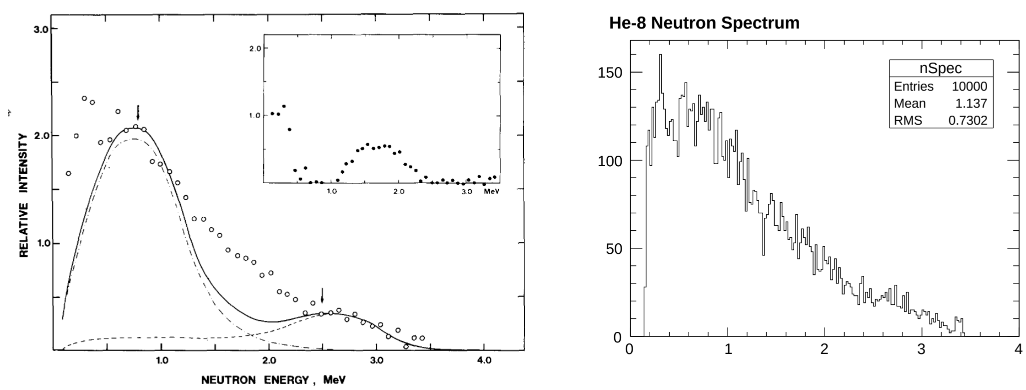

Figure 7: ^{8}He neutron spectrum (the right plot is generated spectrum).

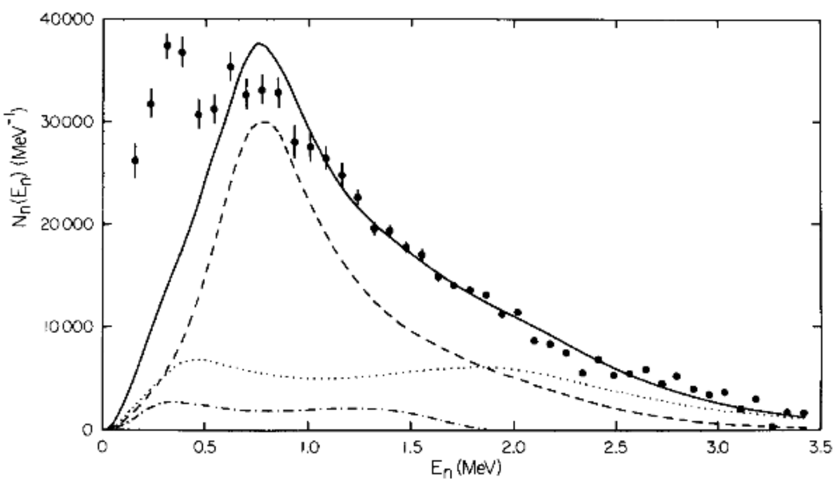

Fig. 1. Experimental and calculated energy spectrum of β-delayed neutrons from ^{8}He. The experimental points are from Björnstad *et al.* [1]). The continuous curve is an *R*-matrix many-level, many-channel best fit. The points for $E_n < 0.4$ MeV were excluded from the fits. The separate contributions to the calculated spectrum from ^{8}Li(n$_0$)^{7}Li(g.s.) (dashed curve), ^{8}Li(n$_1$)^{7}Li(0.48) (dotted curve), and ^{8}Li(t)^{5}He(n)^{4}He (dot-dashed curve) are shown.

Figure 8: ^{8}He neutron spectrum

6 The generator

The package has been transformed from a stand-alone package into a GenDecay style package, it is located at dybgaudi/trunk/Generators/Li9He8Decay. The following are sample codes for usage:

```
  from Li9He8Decay.Helpers import Decay
  decay=Decay()

  decay.decay.Li9fraction = 0.9
#  decay.decay.CompleteDecay = 1

  decay.positioner.Volume = volume
  decay.positioner.Strategy = "FullVolume"
  decay.positioner.Mode = "Uniform"
  decay.positioner.Position = [0,0,0]

  decay.timerator.LifeTime = 1*units.second
  decay.transformer.Volume = volume

  import GenTools
  gtc = GenTools.Configure(genname="Li-9")
  gtc.generator.TimeStamp = int(wallTime)
  gtc.register(decay)
```

There are two configurables. One is "Li9fraction", it is the fraction of ^{9}Li in ^{9}Li/^{8}He isotopes, the default value is 0.9, this value can be configured to reflect the most accurate estimation to date. The other one is "CompleteDecay", the default value is 0, which means only the decays emitting neutrons are considered. If you want the complete decay of ^{9}Li/^{8}He , you need to set this value to 1.

References

[1] Nuclear Physics A510 (1990) 189-208

[2] Nuclear Physics A366 (1981) 461-468

[3] Nuclear Physics A487 (1988) 269-278

[4] Ry Ely and Jen-Chieh Peng, Doc-1067

[5] Viktor Pec, Doc-3566