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IER-579 – Pile Oscillator

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Introduction

- The effective delayed neutron fraction β_{eff}
 - Largely a function of a systems fuel and its energy spectrum
 - An integral response of a multiplying system
- Most benchmarks in ICSBEP don't report a β_{eff} value
- The ones that do report a β_{eff} calculated from MCNP
 - This value is NOT experimentally measured



Why Should We Measure β_{eff} ?

- β_{eff} is essential to understanding the kinetic behavior of the systems we create at NCERC.
- Using β_{eff} alongside k_{eff} to validate nuclear data can help reduce compensating errors due to its different sensitivity profiles
- How could we measure β_{eff} at NCERC?



How Can We Measure β_{eff} ?

- Oscillator Method
 - Sinusoidal reactivity oscillations into a critical system, relate the systems response to the Reactor Transfer Function. Fit experimental data to get β_{eff} and β_i groups.

- Cross Power Spectral Density (CPSD)
 - Frequency domain neutron noise method.
 - Fourier transform of correlation function of two detector signals. Fit experimental data theoretical model to get β_{eff} and Λ



Frequency Domain Reactor Physics

$$\begin{cases} \frac{dn}{dt} = \frac{\rho(t) - \sum_i \beta_i}{\Lambda} n(t) + \sum_i \lambda_i C_i(t) \\ \frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} n(t) - \lambda_i C_i(t) \end{cases}$$

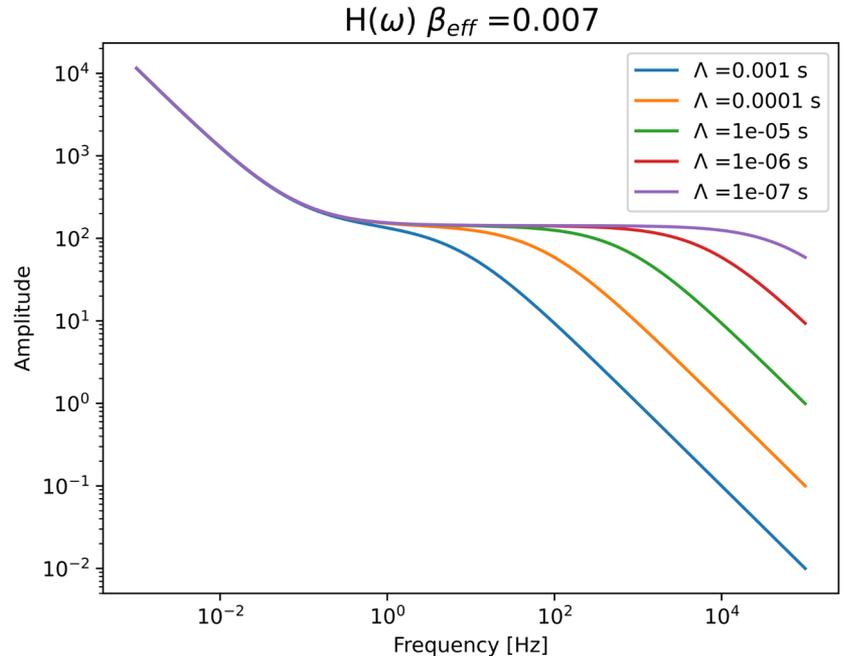
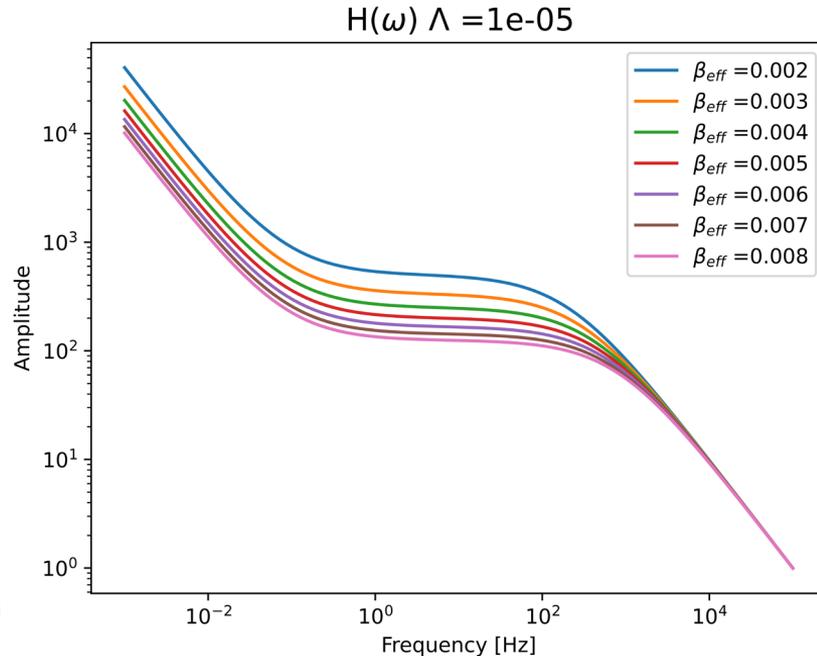
$$H(\omega) = \frac{N(\omega)}{\rho(\omega)N_0} = \left(\omega\Lambda + \sum_i \frac{\omega\beta_i}{\omega + \lambda_i} \right)^{-1}$$

Symbol	Parameter
n	Neutron population
ρ	Reactivity
β_i	i^{th} effective delayed neutron fraction
λ_i	i^{th} effective delayed neutron fraction decay constant
Λ	Prompt neutron generation time
C_i	i^{th} effective delayed neutron fraction precursor concentration
ω	Reactivity perturbation frequency



Zero Power Reactor Transfer Function

- $$H(\omega) = \left(\omega\Lambda + \sum_i \frac{\omega\beta_i}{\omega + \lambda_i} \right)^{-1}$$



Zero Power Reactor Transfer Function

1. Decrease at very low frequencies

When $\omega \ll \lambda_{i,min}$ and $\Lambda \ll \sum \frac{\beta_i}{\omega + \lambda_i}$

$$H(\omega) \Rightarrow \frac{1}{\omega} \left(\sum \frac{\beta_i}{\lambda_i} \right)^{-1} = \frac{\lambda}{\omega \beta_{eff}}$$

2. Plateau at intermediate frequencies

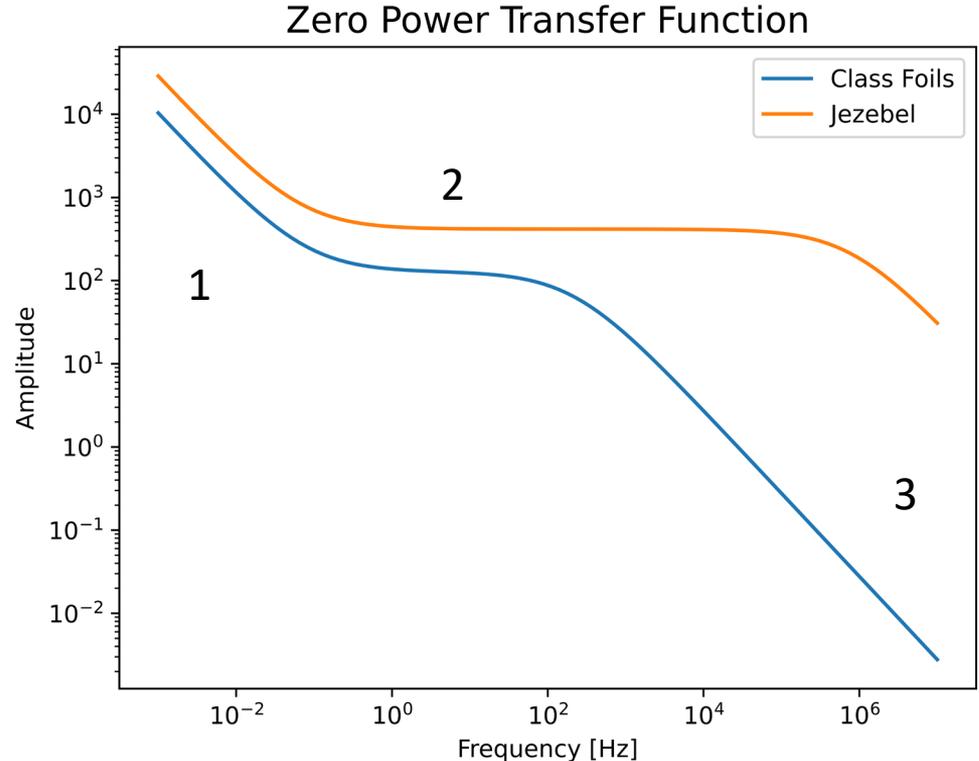
When $\omega \gg \lambda_{i,max}$ and $\Lambda \ll \sum \frac{\beta_i}{\omega + \lambda_i}$

$$H(\omega) \Rightarrow \frac{1}{\omega} \left(\sum \frac{\beta_i}{\omega} \right)^{-1} = \frac{1}{\beta_{eff}}$$

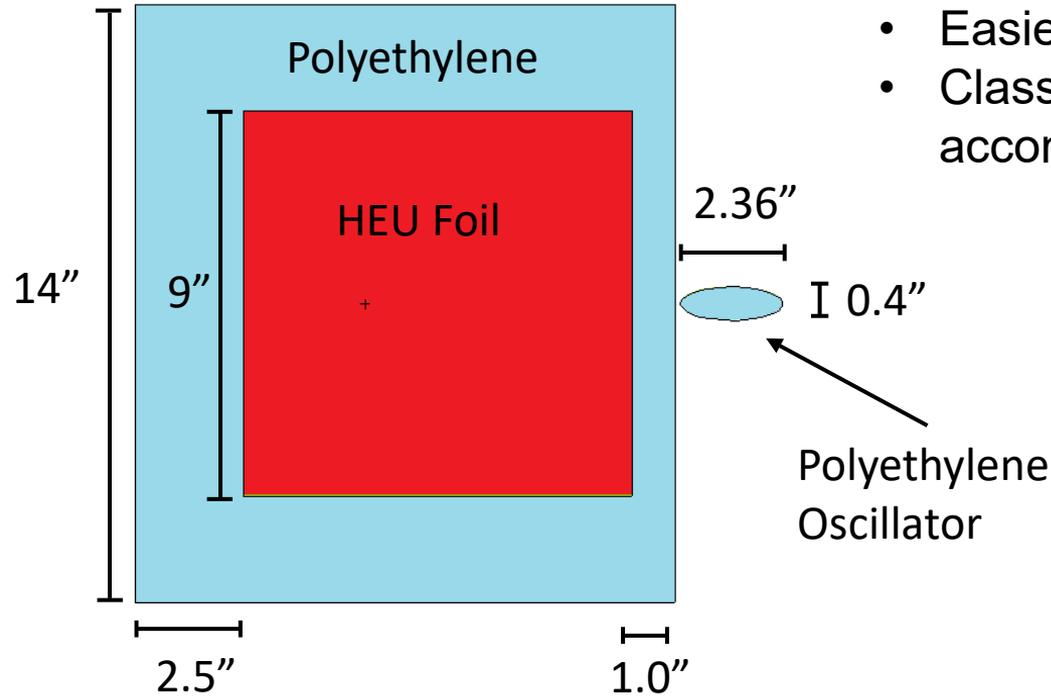
3. Decrease at very high frequencies

When $\omega \gg \lambda_{i,max}$ and $\Lambda \gg \sum \frac{\beta_i}{\omega + \lambda_i}$

$$H(s) \Rightarrow \frac{1}{\omega} (\Lambda)^{-1} = \frac{1}{\omega \Lambda}$$



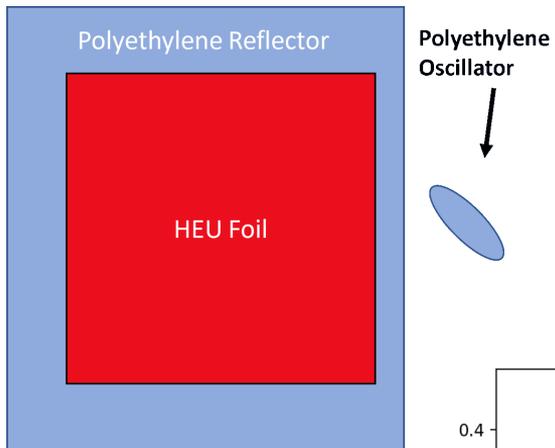
How Can We Do This At NCERC?



- Easiest to demonstrate on thermal system
- Class Foils with 1" reflector to accommodate polyethylene oscillator

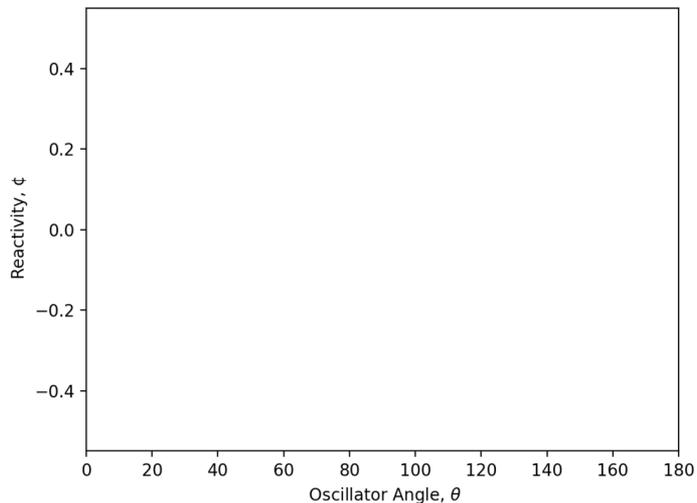


Oscillator Method on Class Foils

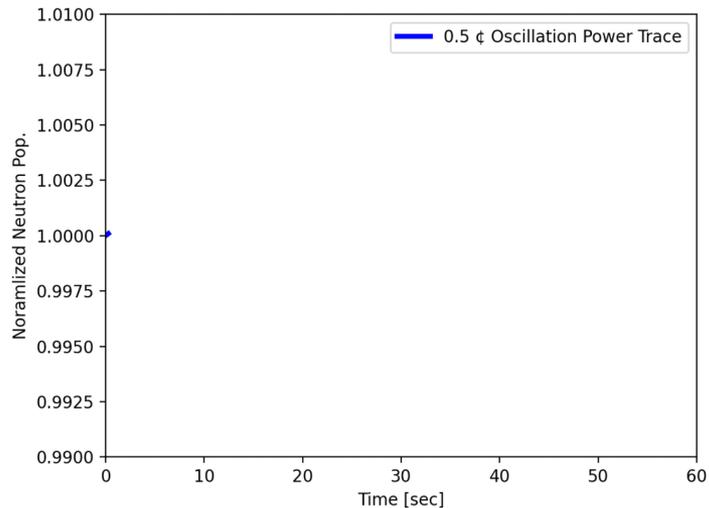


Oscillator rotational frequency of 0.1 Hz

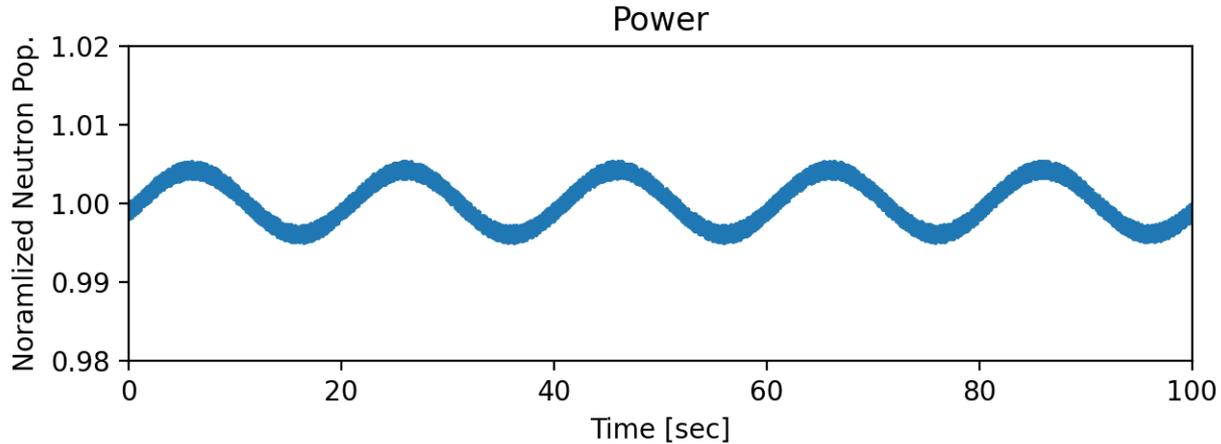
REACTIVITY



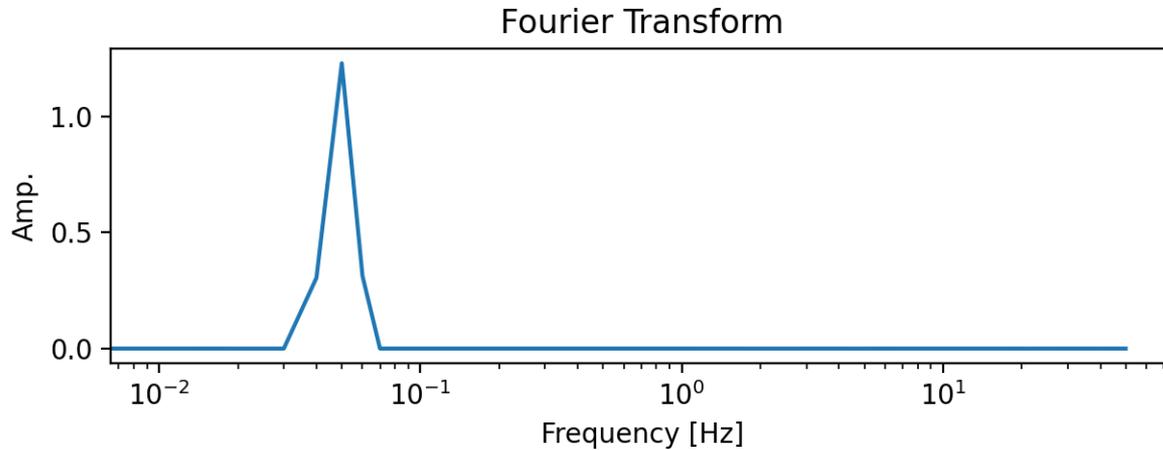
POWER



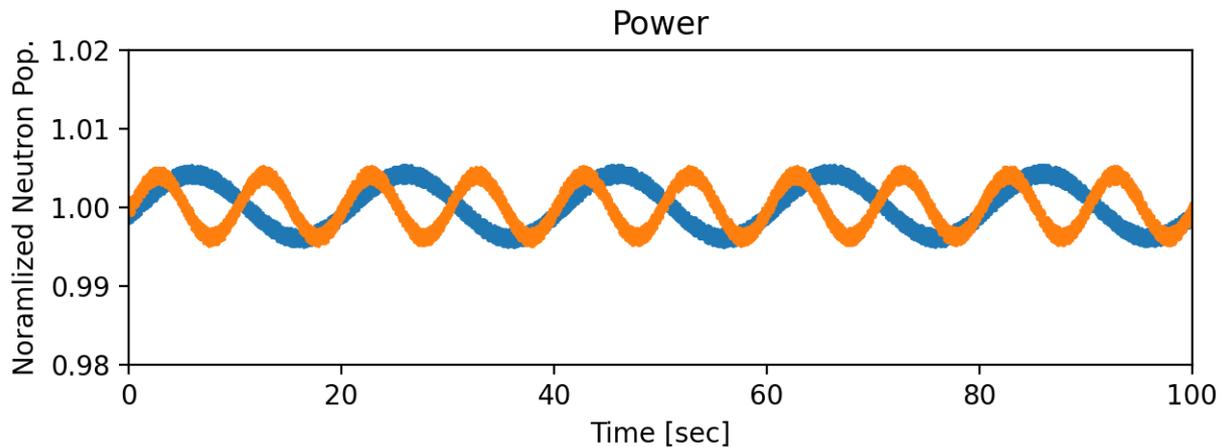
Oscillator Method on Class Foils



- 0.05 Hz

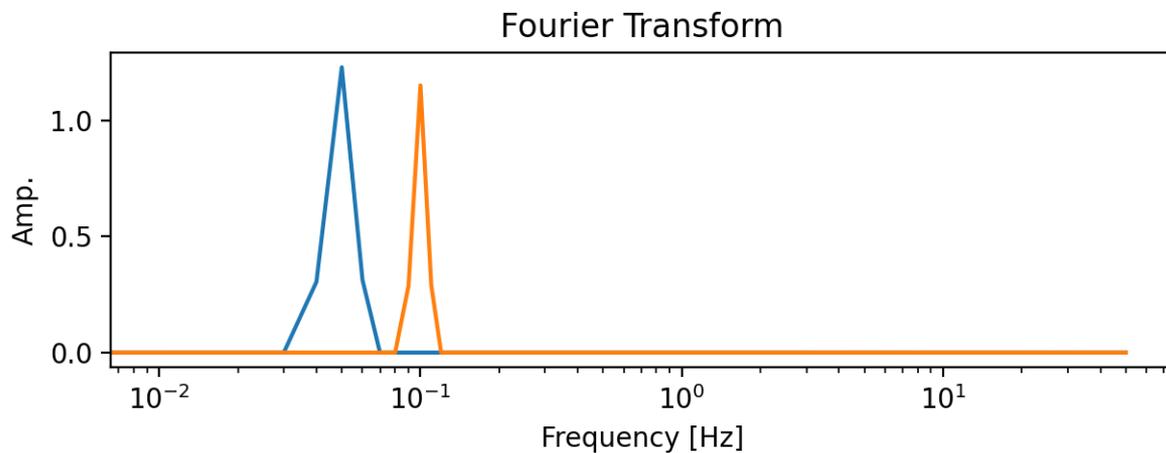


Oscillator Method on Class Foils

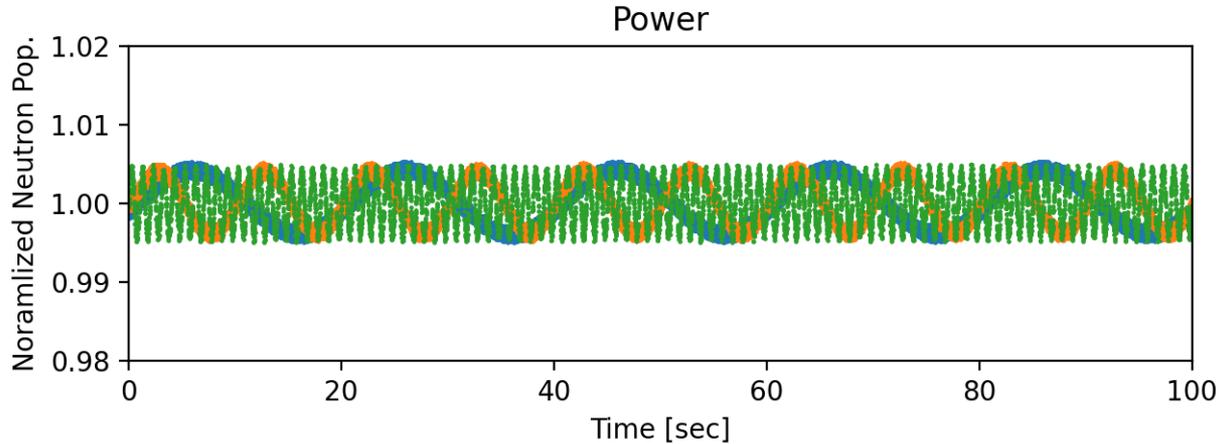


● 0.05 Hz

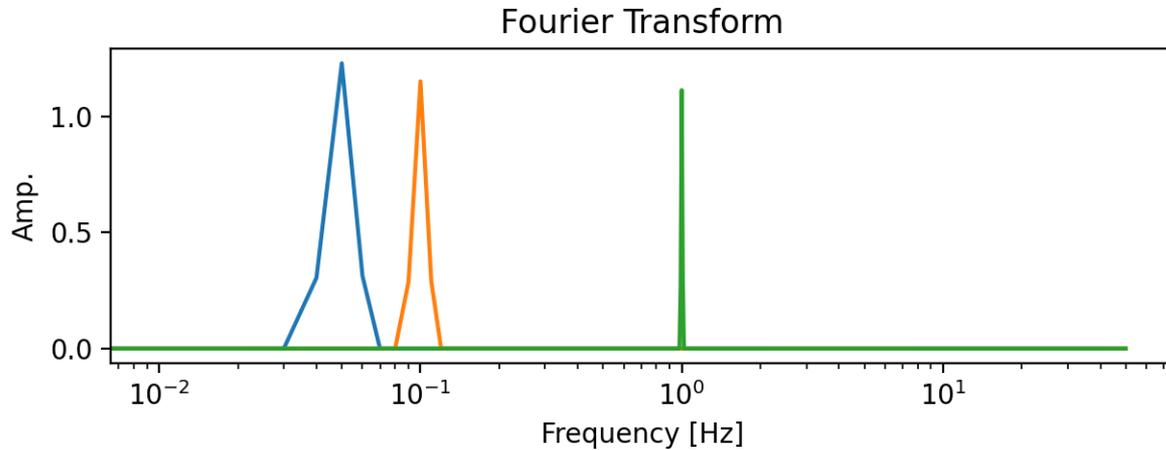
● 0.1 Hz



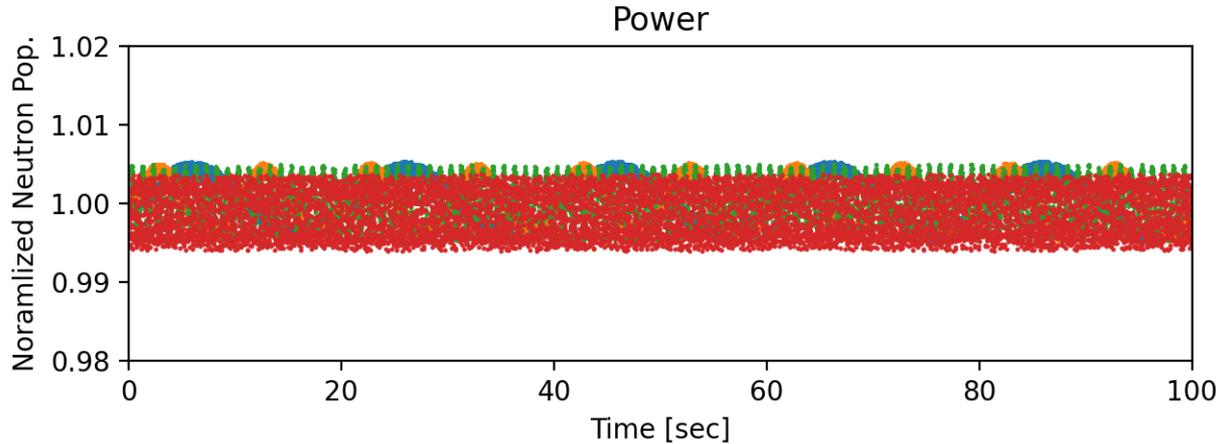
Oscillator Method on Class Foils



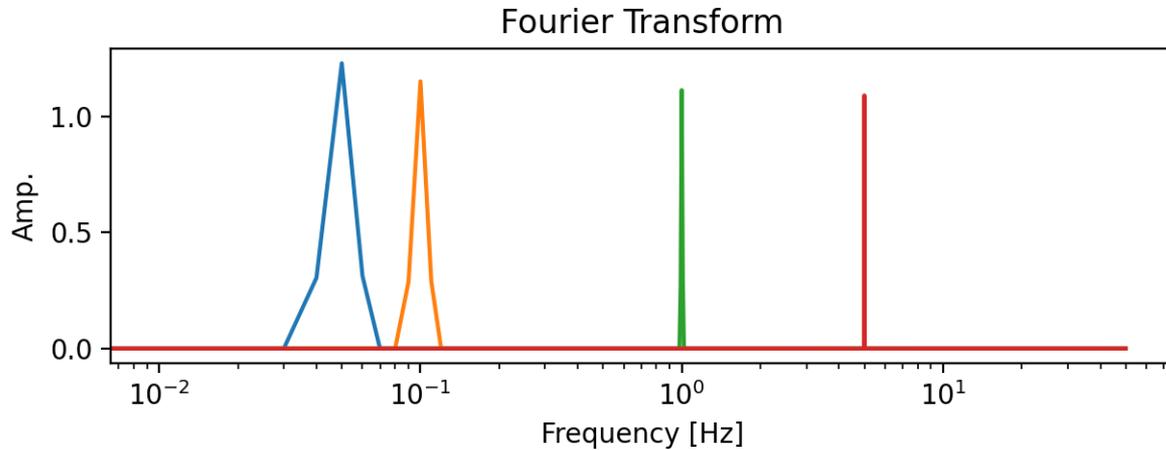
- 0.05 Hz
- 0.1 Hz
- 1 Hz



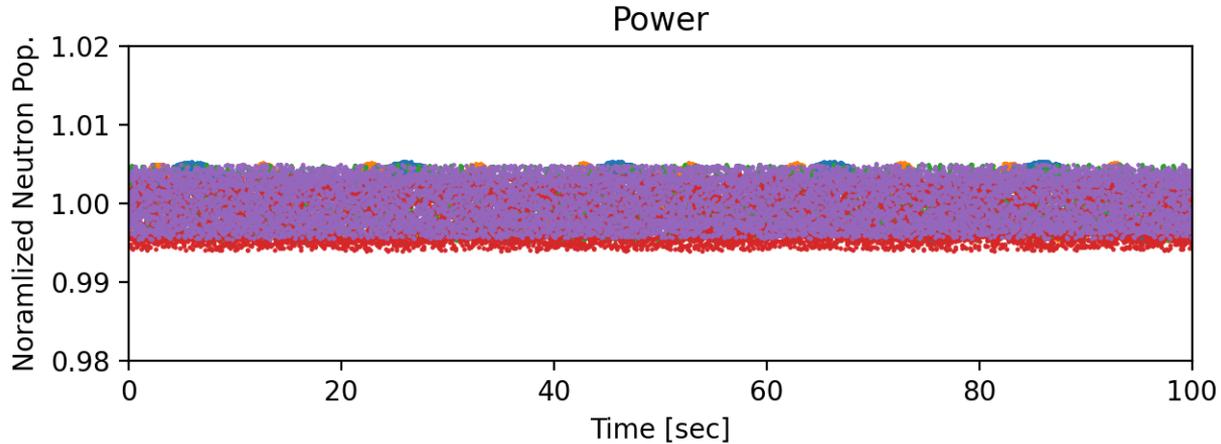
Oscillator Method on Class Foils



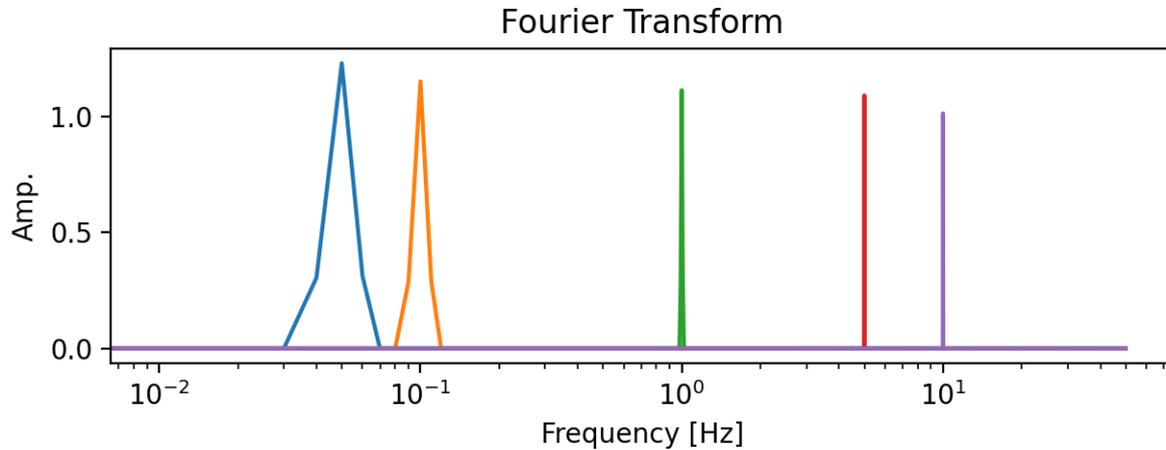
- 0.05 Hz
- 0.1 Hz
- 1 Hz
- 5 Hz



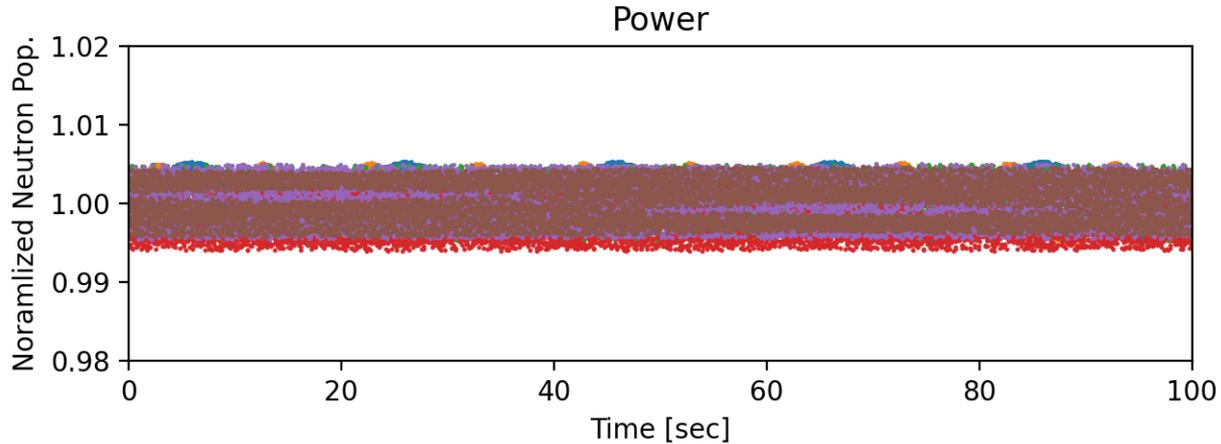
Oscillator Method on Class Foils



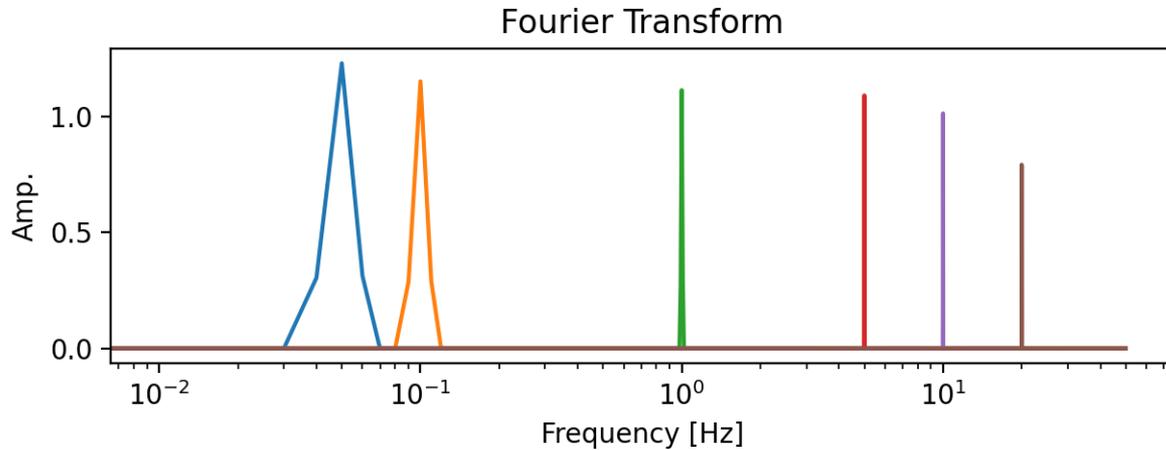
- 0.05 Hz
- 0.1 Hz
- 1 Hz
- 5 Hz
- 10 Hz



Oscillator Method on Class Foils

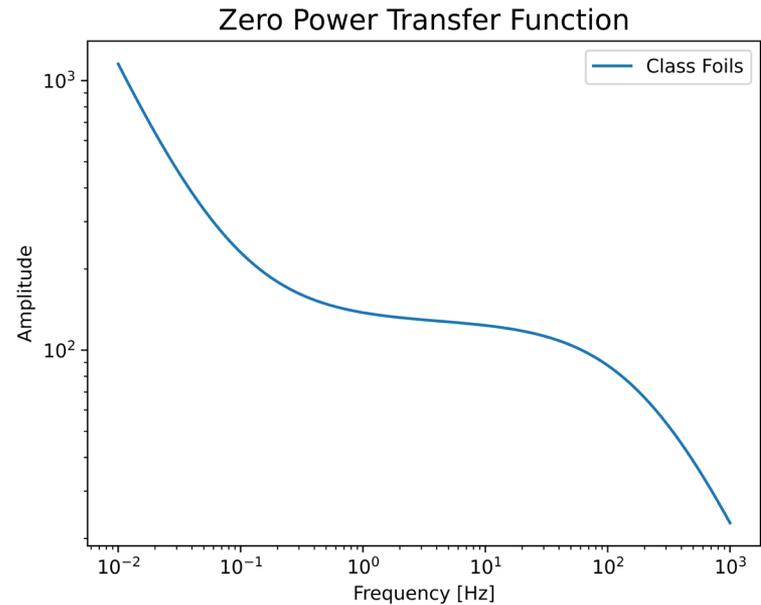
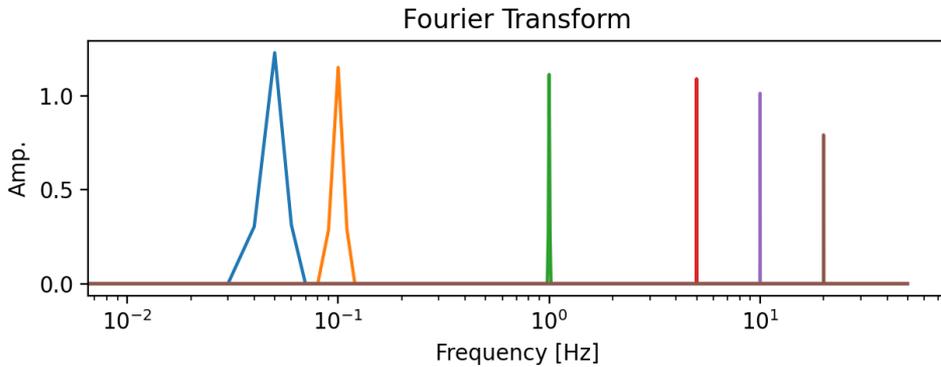


- 0.05 Hz
- 0.1 Hz
- 1 Hz
- 5 Hz
- 10 Hz
- 20 Hz



Oscillator Method on Class Foils

- $$H(\omega) = \left(\omega\Lambda + \sum_i \frac{\omega\beta_i}{\omega + \lambda_i} \right)^{-1}$$



CPSD on Class Foils

- The CPSD is defined as the Fourier transform of the cross-correlation between two detectors:

$$CPSD \equiv \mathcal{F} \left\{ \frac{1}{2T} \int_{-T}^T c_1(t)c_2(t + \tau)dt \right\} = 2 \frac{F}{D} \frac{1}{1 + (\omega/\alpha)^2}$$

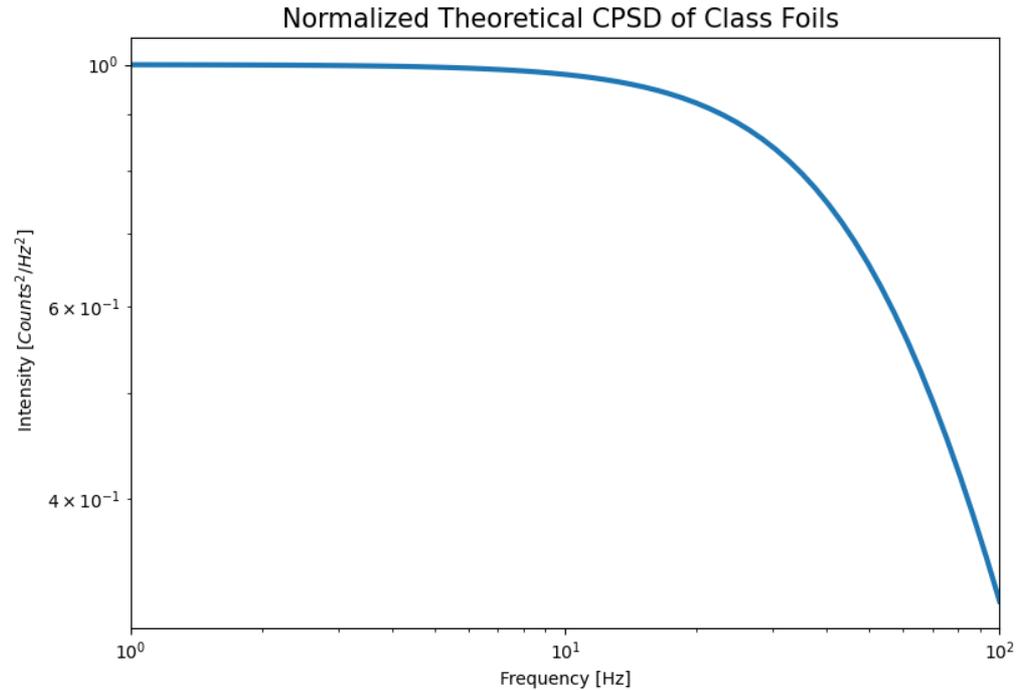
Symbol	Parameter
F	Integral fission rate [fissions/sec]
D	Diven Factor
α	Prompt neutron decay constant [s^{-1}]
ω	Frequency [Hz]



CPSD on Class Foils

- $$CPSD \equiv 2 \frac{F}{D} \frac{1}{(\beta_{eff} - \rho)^2 + 1 + (\omega/\alpha)^2}$$

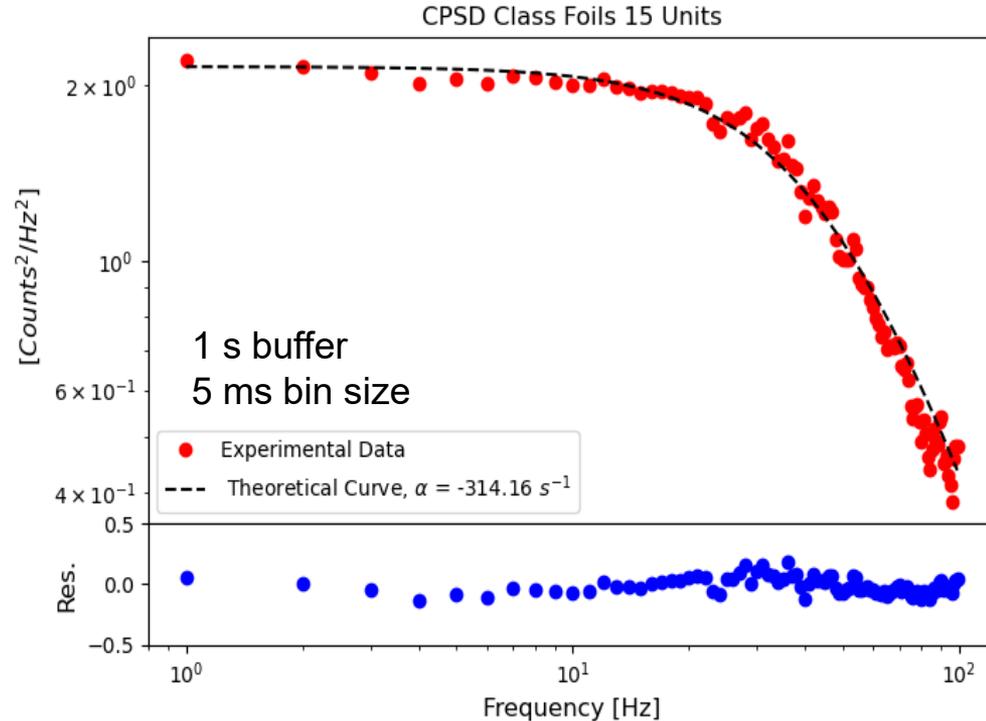
Parameter	Value
β_{eff}	0.00787
Λ	36.5e-6 s
D	0.8
ρ	0



CPSD on Class Foils (from 9/17/2017)

- Binned time-tagged neutron count data from four He-3 detectors located inside 15-unit polyethylene Class Foils experiment
- Only six minutes worth of data
- $k_{eff} = 0.993$

	Method	α [s^{-1}]
McKenzie, 2018	Rossi- α	-340.4 ± 5.3
This Work	CPSD	-314.2 ± 21.5
	MCNP6.2	-307.7 ± 9.2



CPSD on Class Foils

- Fit CPSD to Lorentzian distribution
- To get β_{eff} this would have to be done at delayed critical and we would need to know the integral fission rate
- This would additionally give us the prompt neutron generation time, Λ

$$CPSD \equiv 2 \frac{F}{D} \frac{1}{1 + (\omega/\alpha)^2}$$

$$f(\omega) = \frac{x_1}{1 + (\omega/x_2)^2}$$

$$\beta_{eff} - \rho = \sqrt{\frac{2D}{F} \frac{1}{x_1}}, \quad \Lambda = \frac{\beta_{eff} - \rho}{2\pi x_2}$$



Summary

Parameter		Oscillator	CPSD
β_i	i^{th} effective delayed group	X	
β_{eff}	Effective delayed neutron fraction	X	X
Λ	Prompt neutron generation time		X



Conclusions

- Gaining the capability of measuring β_{eff} at could aid in nuclear data evaluation due to its unique sensitivities and better characterize the systems we build
- An Oscillator-CPSD experiment on the Class Foils can be the first step and establishing this capability
- Lessons learned from this experiment would inform future β_{eff} measurement efforts at NCERC



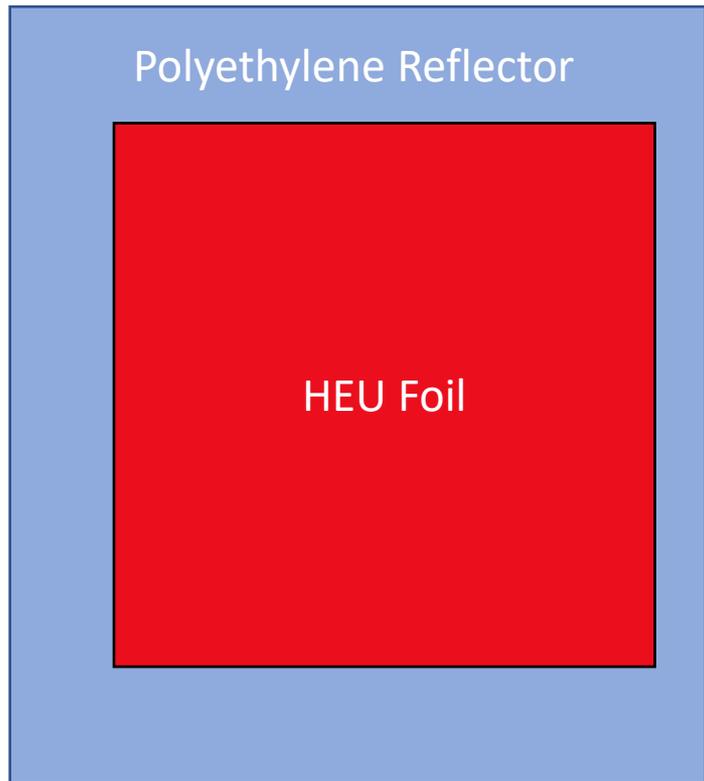
Acknowledgements

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Questions?





**Polyethylene
Oscillator**

