Ar, N2, Xe interactions and light emission

Francesco P. (ideas)
Flavio (plots)

Francesco P.

1) the ArAr* excited dimer (AA) disappears by scintillation (at 128 nm), quenching through nitrogen, and shifting to ArXe* (AX) through the process ArAr* + Xe -> ArXe* + Ar:

$$\frac{dAA}{dt} = -\frac{AA}{\tau_{128}} - \frac{AA}{\tau_{N2}} - \frac{AA}{\tau_{AX}} = -\frac{AA}{\tau_{TA}}$$

FPP:
The role of ArXe* may be large, dominant at low Xe doping (never seen/explored before)

2) the ArXe* dimer is formed from ArAr* dimer and disappears through scintillation (at 150 nm) and shifting to XeXe* (XX) through the process ArXe* + Xe -> XeXe* + Ar:

$$\frac{dAX}{dt} = +\frac{AA}{\tau_{AX}} - \frac{AX}{\tau_{150}} - \frac{AX}{\tau_{XX}} = +\frac{AA}{\tau_{AX}} - \frac{AX}{\tau_{TX}}$$

3) the XeXe* dimer is formed from the ArXe* dimer and disappears through scintillation (at 175 nm):

$$\frac{dXX}{dt} = +\frac{AX}{\tau_{XX}} - \frac{XX}{\tau_{175}}$$

Same Eqs. as before (FPP), expressed in terms of Rate Constants and Concentrations

$$\frac{d[Ar_2^*]_T}{dt} = -\frac{1}{\tau_{128_T}}[Ar_2^*]_T - k_Q[N_2][Ar_2^*]_T - k_{EnT1}[Xe][Ar_2^*]_T$$

$[Ar_2^*]_T = [Ar_2^*]_T(t)$ *in* ppm

$$\frac{d[(ArXe)^*]}{dt} = +k_{EnT1}[Xe][Ar_2^*]_T - \frac{1}{\tau_{149}}[(ArXe)^*] - k_{EnT2}[Xe][(ArXe)^*]$$

$[Ar_2^*]_T = [Ar_2^*]_T(t)$

$[(ArXe)^*] = [(ArXe)^*](t)$

$$\frac{d[Xe_2^*]}{dt} = +k_{EnT2}[Xe][(ArXe)^*] - \frac{1}{\tau_{174}}[Xe_2^*]$$

$[(ArXe)^*] = [(ArXe)^*](t)$

$[Xe_2^*] = [Xe_2^*](t)$

EPL, 117 (2017) 39002
Photon emission and atomic collision processes in two-phase argon doped with xenon and nitrogen
A. Buzulutskov

The European Physical Journal C volume 73
Ion-beam excitation of liquid argon
M. Hofmann et al.,

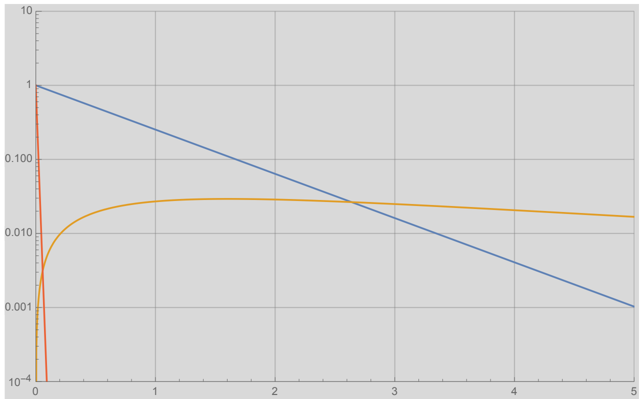
Parameters:

- $\tau_{128_T} = 1.3\ \mu s$ [Ar_2* Triplet Dcy Time]
- $k_Q\ =\ 0.11\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$ [N_2 Quenching rate Constant]
- $[N_2]\ =\ 5\ \text{ppm}$ [Actual N_2 Concentration]
- $[Xe]\ =\ xx\ \text{ppm}$ [Dope *n*]
- $k_{EnT1}\ =\ 0.17\ \ \text{ppm}^{-1}\ \mu\text{s}^{-1}$ [Xe En Transfer (1st step) ArXe* formation]
- $\tau_{149}\ =\ 5.1\ \mu\text{s}$ [(ArXe)* Dcy Time]
- $k_{EnT2} = 0.05\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$ [Xe En Transfer (2nd step) Xe_2* formation]
- $\tau_{174}\ =\ 0.022\ \mu\text{s}$ [Xe_2* Triplet Dcy Time]

The cumulative Xe concentrations are:
(1) - 1.1 ppm
(2) - 4.2 ppm
(3) - 11.6 ppm
(4) - 16.0 ppm
(5) - 18.8 ppm

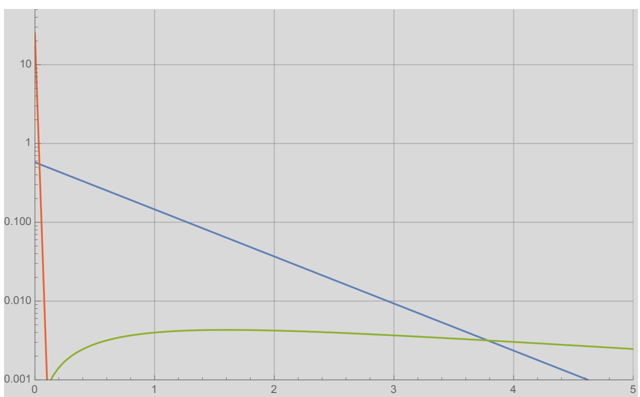
Parameters:

- $f_S = 0.25$
- $\tau_{128_S} = 0.010\ \mu\text{s}$
- $f_T = 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q = 0.11\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$
- $[N_2] = 5\ \text{ppm}$
- $[Xe] = \frac{1.1}{3.3}\ \text{ppm}$ (Dope 1)
- $k_{EnT1} = 0.17\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$
- $\tau_{149} = 5.1\ \mu s$
- $k_{EnT2} = 0.05\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$
- $\tau_{174} = 0.022\ \mu\text{s}$



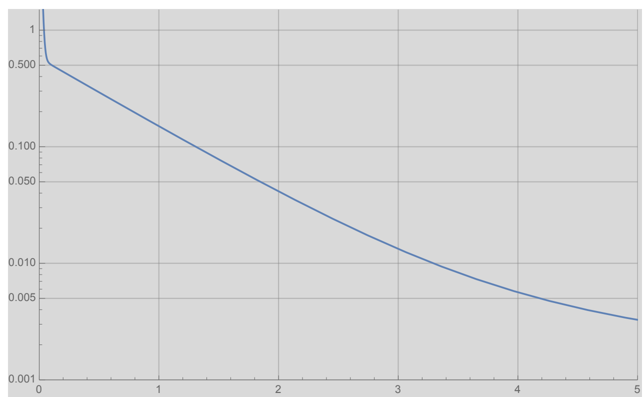
Solution of State Equations

Dope 1

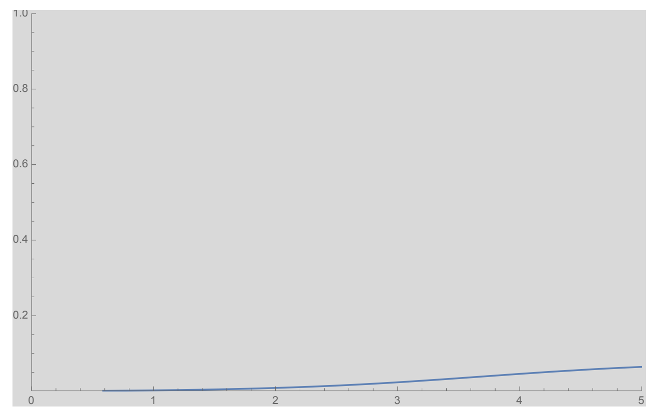


Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn’s

Note: ArXe > Xe (not visible)



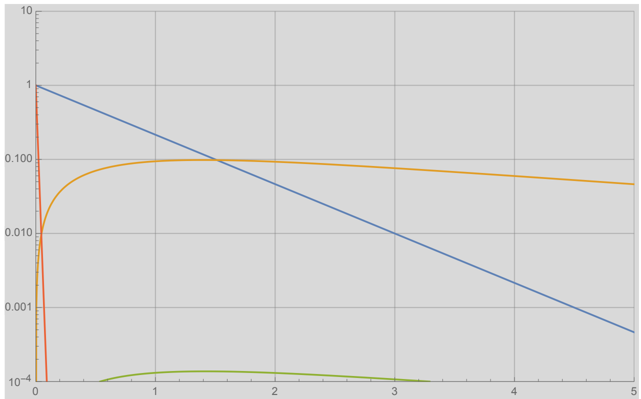
No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

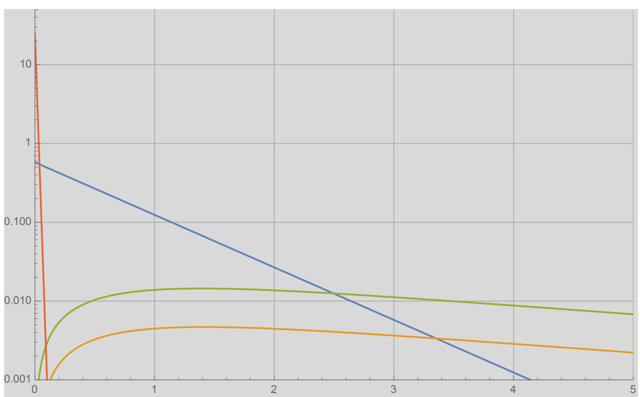
Parameters:

- $f_S \;=\; 0.25$
- $\tau_{128_S} \;=\; 0.010\ \mu s$
- $f_T \;=\; 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q \;=\; 0.11\ \text{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] \;=\; 5\ \text{ppm}$
- $[Xe] \;=\; \frac{4.2}{3.3}\ \text{ppm}$ (Dope 1)
- $k_{EnT1} \;=\; 0.17\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} \;=\; 5.1\ \mu s$
- $k_{EnT2} \;=\; 0.05\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} \;=\; 0.022\ \mu s$



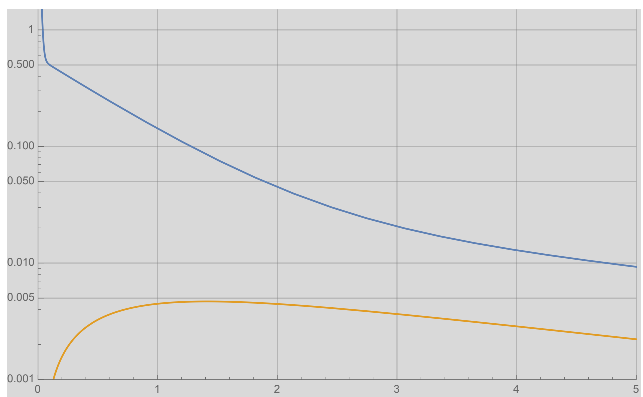
Solution of State Equations

Dope 2

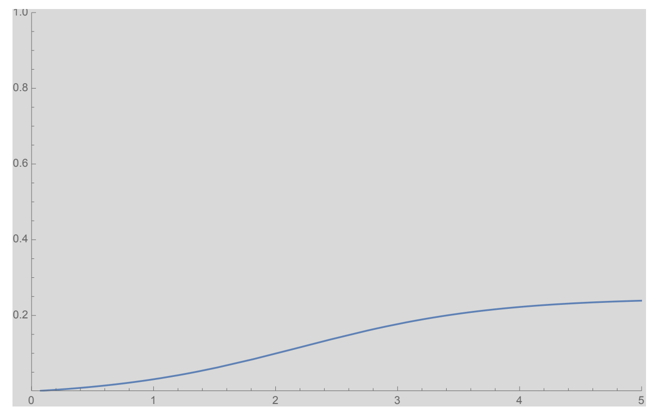


Ar$_S$, Ar$_T$, ArXe, Xe Scintillation Light Time Distribution Fcn's

Note: ArXe > Xe



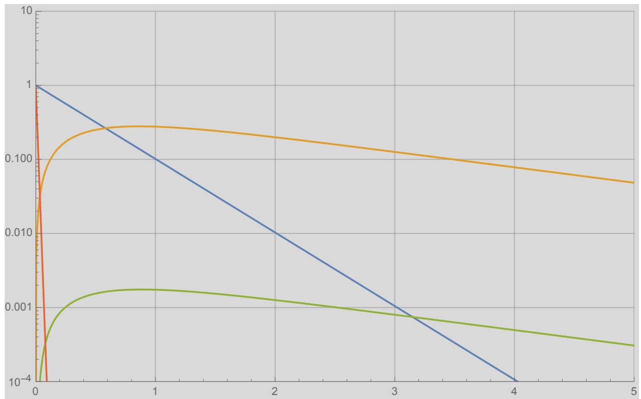
No Quartz (Ar$_S$, Ar$_T$+ArXe+Xe) & **Quartz** (Xe) detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar$_T$+ArXe+Xe) Ratio detectable Light Time Distribution

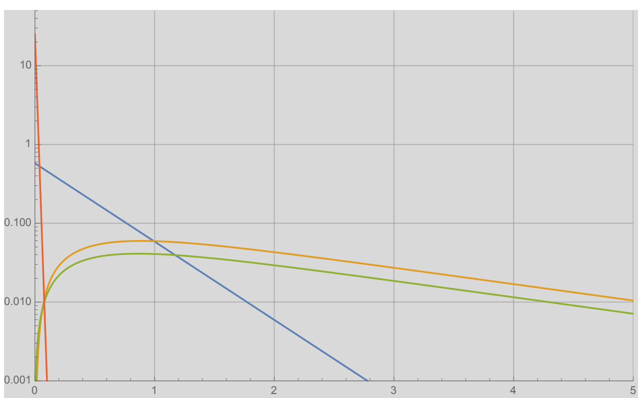
Parameters:

- $f_S = 0.25$
- $\tau_{128_S} = 0.010\ \mu s$
- $f_T = 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q = 0.11\ \text{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] = 5\ \text{ppm}$
- $[Xe] = \frac{18.8}{3.3}\ \text{ppm}$ (Dope 1)
- $k_{EnT1} = 0.17\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} = 5.1\ \mu s$
- $k_{EnT2} = 0.05\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} = 0.022\ \mu s$

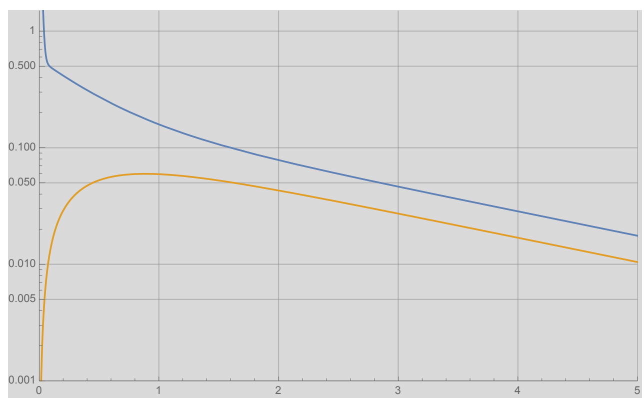


Solution of State Equations

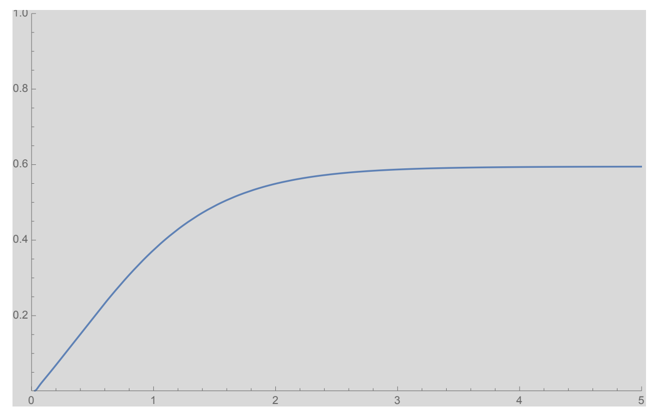
Dope 5



Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's



No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

$$\frac{d[Ar_2^*]_T}{dt} = -\frac{1}{\tau_{128_T}}[Ar_2^*]_T - k_Q[N_2][Ar_2^*]_T - k_{EnT1}[Xe][Ar_2^*]_T$$

$[Ar_2^*]_T = [Ar_2^*]_T(t)$ *in* ppm

$$\frac{d[(ArXe)^*]}{dt} = +k_{EnT1}[Xe][Ar_2^*]_T - \frac{1}{\tau_{149}}[(ArXe)^*] - k_{EnT2}[Xe][(ArXe)^*]$$

$[Ar_2^*]_T = [Ar_2^*]_T(t)$

$[(ArXe)^*] = [(ArXe)^*](t)$

$$\frac{d[Xe_2^*]}{dt} = +k_{EnT2}[Xe][(ArXe)^*] - \frac{1}{\tau_{174}}[Xe_2^*]$$

$[(ArXe)^*] = [(ArXe)^*](t)$

$[Xe_2^*] = [Xe_2^*](t)$

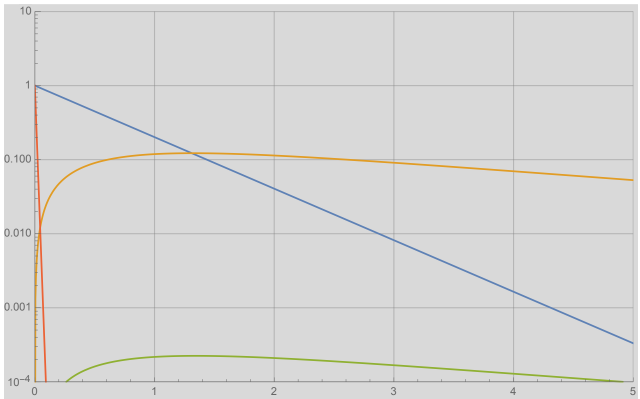
Parameters:

- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q = 0.11\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$
- $[N_2] = 5$ ppm
- $[Xe] = xx$ ppm (Dope *n*)
- k_{EnT1} free parameter
- $\tau_{149} = 5.1\ \mu$s
- k_{EnT2} free parameter
- $\tau_{174} = 0.022\ \mu$s

The cumulative Xe concentrations are:
(1) - 1.1 ppm
(2) - 4.2 ppm
(3) - 11.6 ppm
(4) - 16.0 ppm
(5) - 18.8 ppm

Parameters:

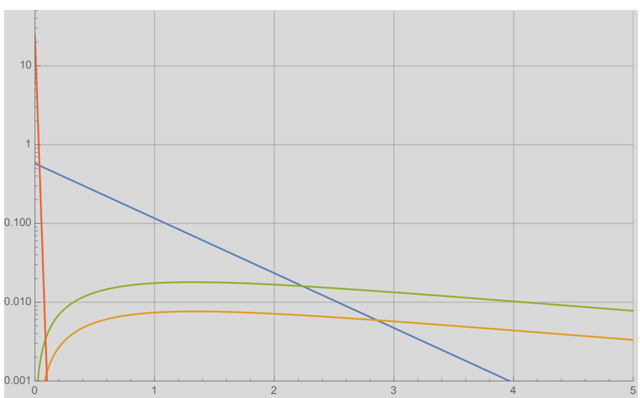
- $f_S = 0.25$
- $\tau_{128_S} = 0.010\ \mu s$
- $f_T = 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q = 0.11\ \text{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] = 5\ \text{ppm}$
- $[Xe] = \frac{1.1}{3.3}\ \text{ppm}$ (Dope 1)
- $k_{EnT1} = 0.17 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} = 5.1\ \mu s$
- $k_{EnT2} = 0.05 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} = 0.022\ \mu s$



Solution of State Equations

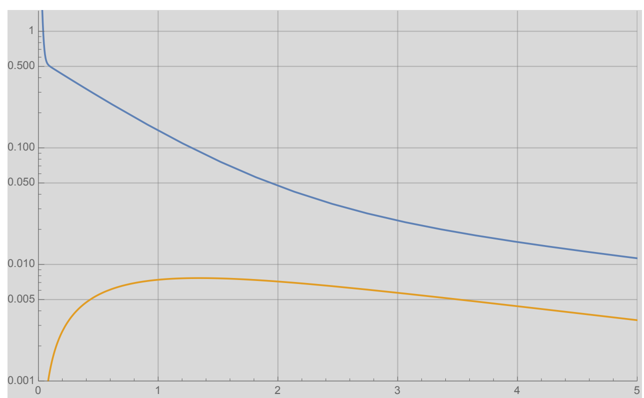
Dope 1

Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5

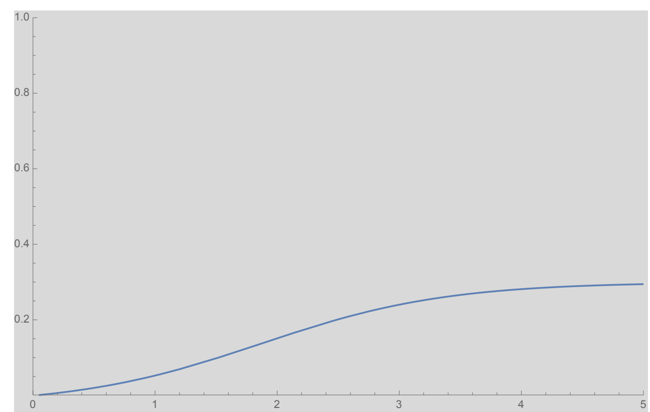


Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's

Note: ArXe > Xe



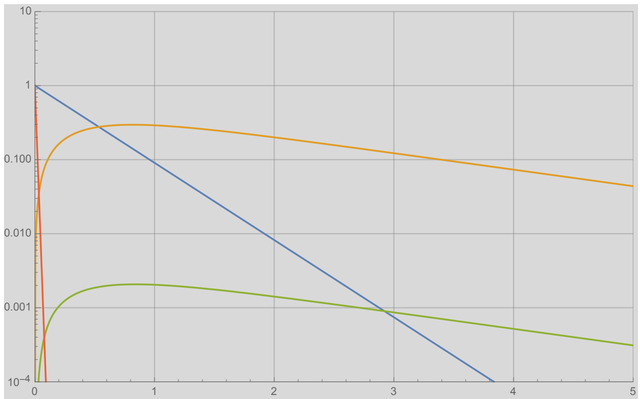
No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

Parameters:

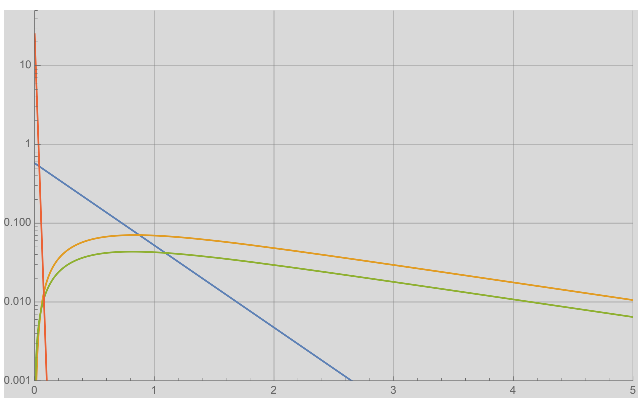
- $f_S = 0.25$
- $\tau_{128_S} = 0.010\ \mu s$
- $f_T = 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q = 0.11\ \text{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] = 5\ \text{ppm}$
- $[Xe] = \frac{4.2}{3.3}\ \text{ppm}$ (Dope 2)
- $k_{EnT1} = 0.17 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} = 5.1\ \mu s$
- $k_{EnT2} = 0.05 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} = 0.022\ \mu s$



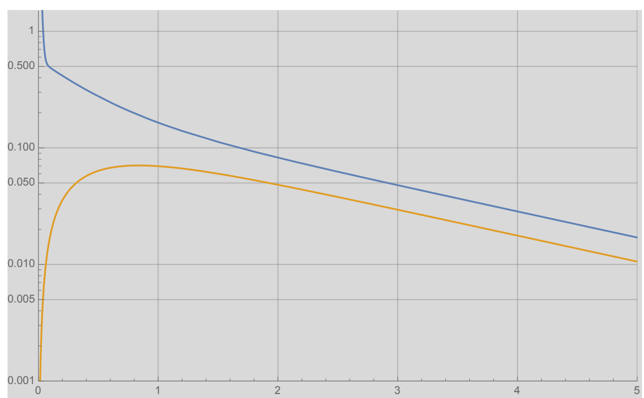
Solution of State Equations

Dope 2

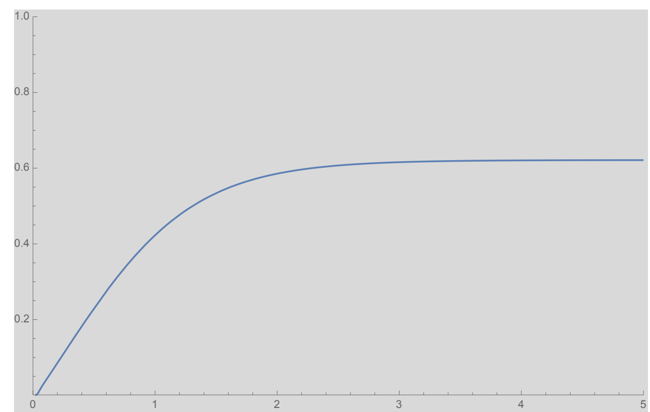
Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5



Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's



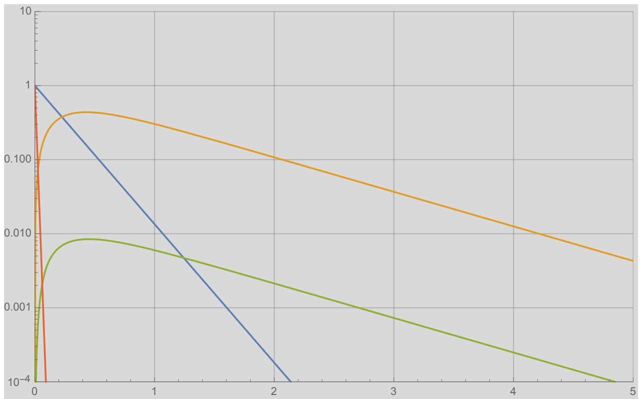
No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

Parameters:

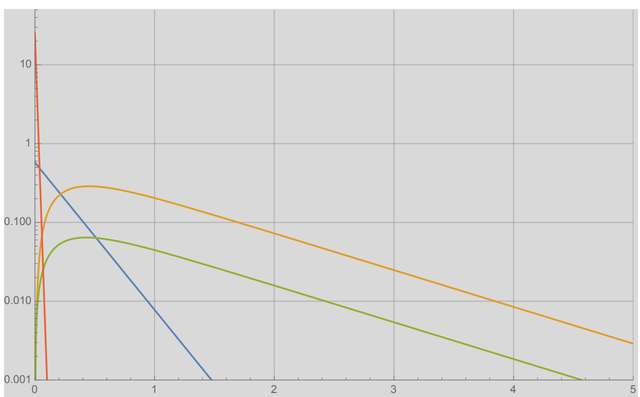
- $f_S \;=\; 0.25$
- $\tau_{128_S} \;=\; 0.010\ \mu s$
- $f_T \;=\; 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q \;=\; 0.11\ \text{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] \;=\; 5\ \text{ppm}$
- $[Xe] \;=\; \frac{11.6}{3.3}\ \text{ppm}$ (Dope 3)
- $k_{EnT1} \;=\; 0.17 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} \;=\; 5.1\ \mu s$
- $k_{EnT2} \;=\; 0.05 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} \;=\; 0.022\ \mu s$



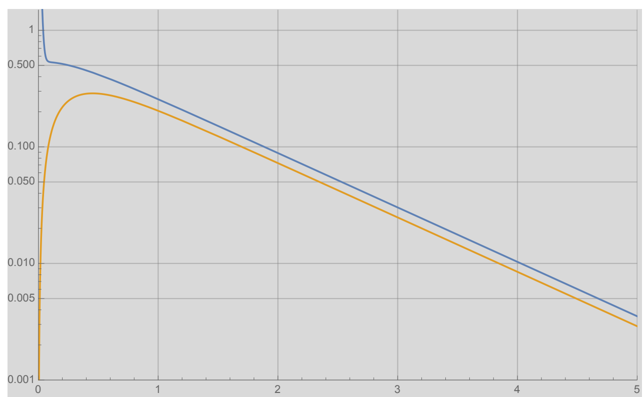
Solution of State Equations

Dope 3

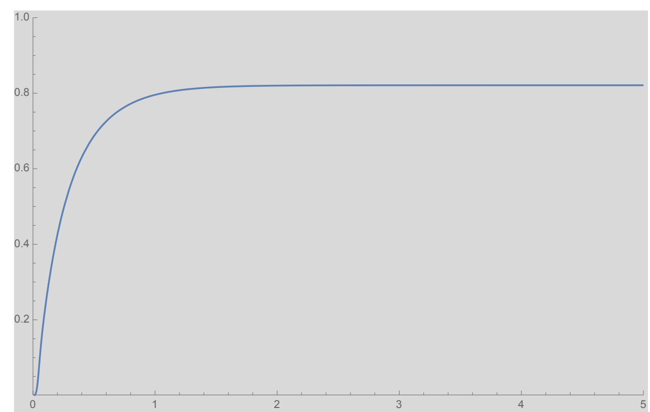
Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5



Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's



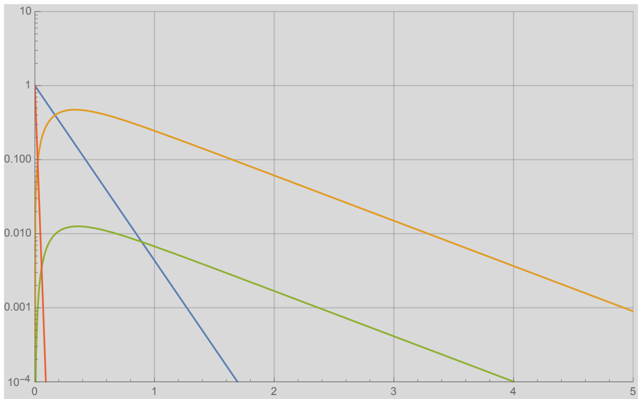
No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

Parameters:

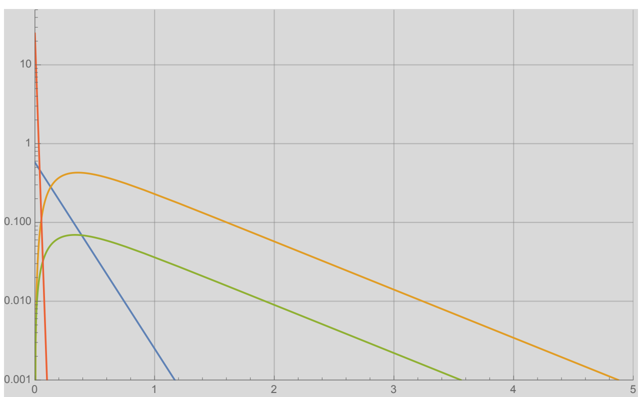
- $f_S = 0.25$
- $\tau_{128_S} = 0.010\ \mu s$
- $f_T = 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q = 0.11\ \text{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] = 5\ \text{ppm}$
- $[Xe] = \frac{16.0}{3.3}\ \text{ppm}$ (Dope 4)
- $k_{EnT1} = 0.17 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} = 5.1\ \mu s$
- $k_{EnT2} = 0.05 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} = 0.022\ \mu s$



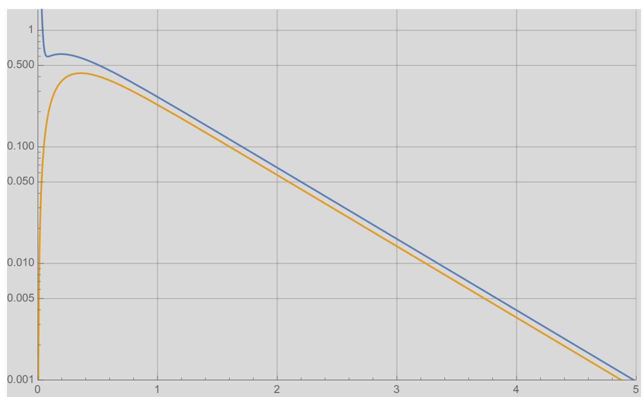
Solution of State Equations

Dope 4

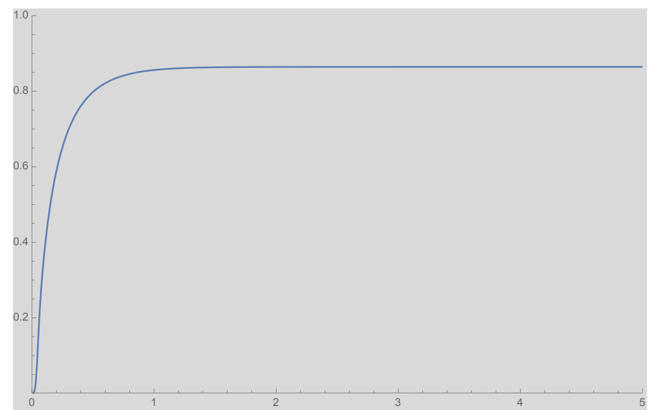
Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5



Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's



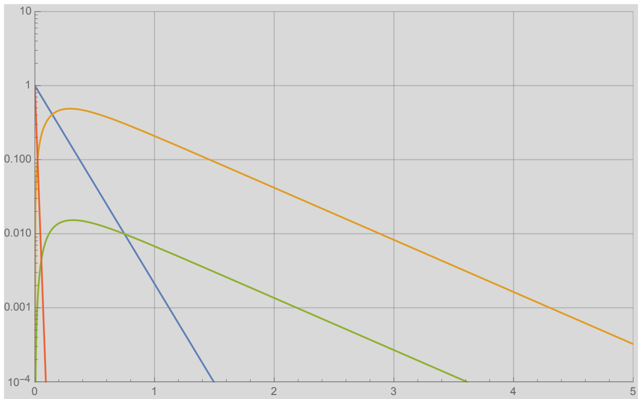
No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

Parameters:

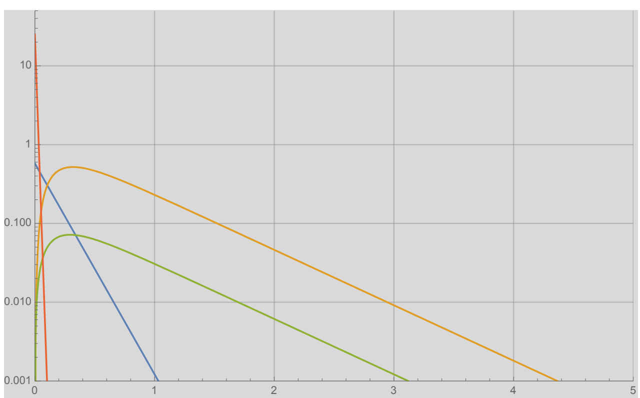
- $f_S \;=\; 0.25$
- $\tau_{128_S} \;=\; 0.010\ \mu s$
- $f_T \;=\; 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q \;=\; 0.11\ \text{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] \;=\; 5\ \text{ppm}$
- $[Xe] \;=\; \frac{18.8}{3.3}\ \text{ppm}$ (Dope 5)
- $k_{EnT1} \;=\; 0.17 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} \;=\; 5.1\ \mu s$
- $k_{EnT2} \;=\; 0.05 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} \;=\; 0.022\ \mu s$



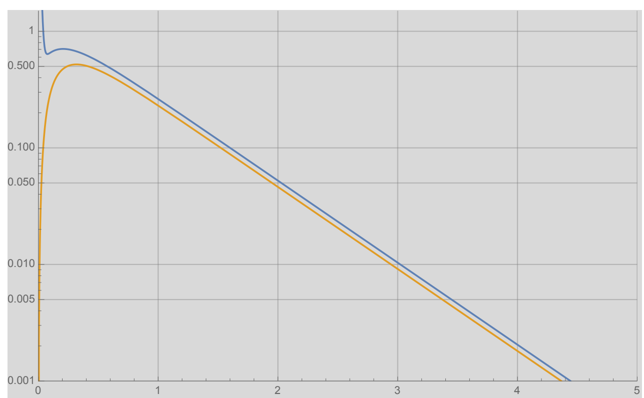
Solution of State Equations

Dope 5

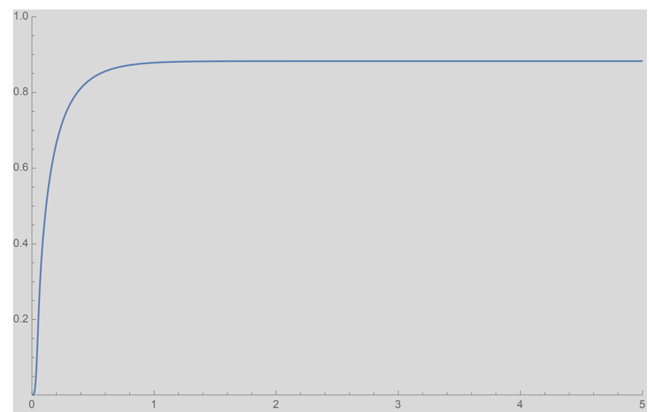
Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5



Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's



No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

$$\frac{d[Ar_2^*]_T}{dt} = -\frac{1}{\tau_{128_T}}[Ar_2^*]_T - k_Q[N_2][Ar_2^*]_T - k_{EnT1}[Xe][Ar_2^*]_T$$

$[Ar_2^*]_T = [Ar_2^*]_T(t)$ in ppm

$$\frac{d[(ArXe)^*]}{dt} = +k_{EnT1}[Xe][Ar_2^*]_T - \frac{1}{\tau_{149}}[(ArXe)^*] - k_{EnT2}[Xe][(ArXe)^*]$$

$[Ar_2^*]_T = [Ar_2^*]_T(t)$

$[(ArXe)^*] = [(ArXe)^*](t)$

$$\frac{d[Xe_2^*]}{dt} = +k_{EnT2}[Xe][(ArXe)^*] - \frac{1}{\tau_{174}}[Xe_2^*]$$

$[(ArXe)^*] = [(ArXe)^*](t)$

$[Xe_2^*] = [Xe_2^*](t)$

Parameters:

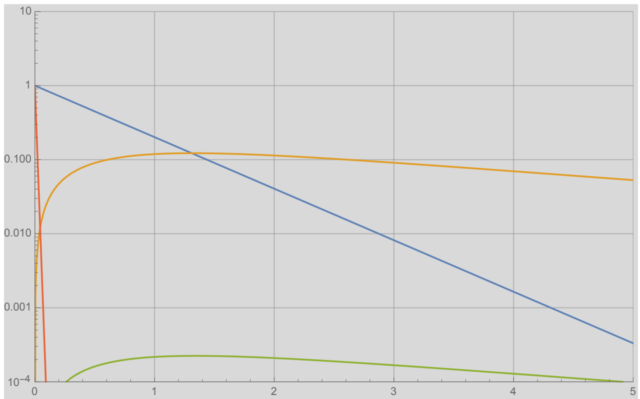
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q = 0.11$ ppm^{-1} μs^{-1}
- $[N_2] = 5$ ppm
- $[Xe] = xx$ ppm (Dope *n*)
- k_{EnT1} free parameter
- τ_{149} free parameter
- k_{EnT2} free parameter
- $\tau_{174} = 0.022\ \mu$s

The cumulative Xe concentrations are:

(1) - 1.1 ppm
(2) - 4.2 ppm
(3) - 11.6 ppm
(4) - 16.0 ppm
(5) - 18.8 ppm

Parameters:

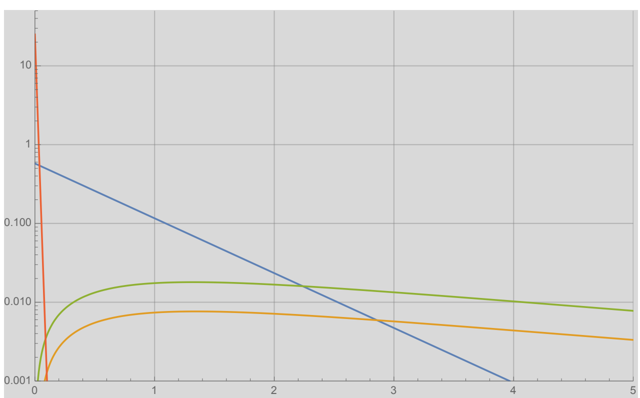
- $f_S \;=\; 0.25$
- $\tau_{128_S} \;=\; 0.010\ \mu s$
- $f_T \;=\; 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q \;=\; 0.11\ \text{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] \;=\; 5\ \text{ppm}$
- $[Xe] \;=\; \frac{1.1}{3.3}\ \text{ppm}$ (Dope 1)
- $k_{EnT1} \;=\; 0.17 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} = = 5.1\ \mu s$
- $k_{EnT2} \;=\; 0.05 \times 5\ \text{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} \;=\; 0.022\ \mu s$



Solution of State Equations

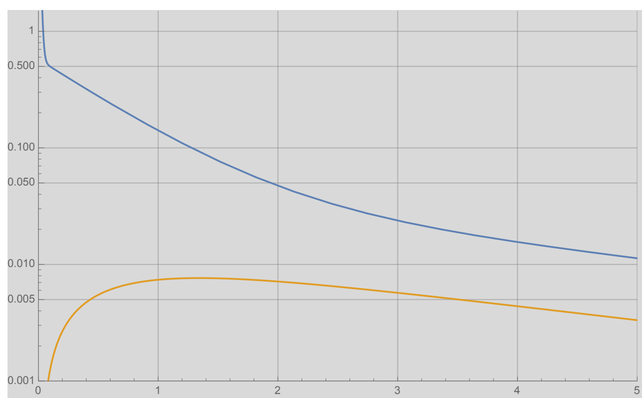
Dope 1

Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5

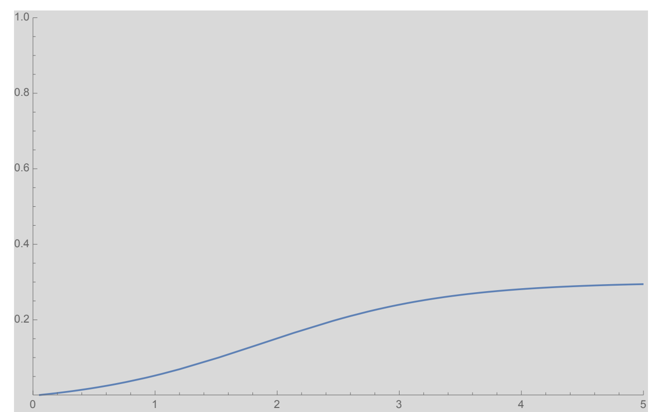


Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's

Note: ArXe > Xe



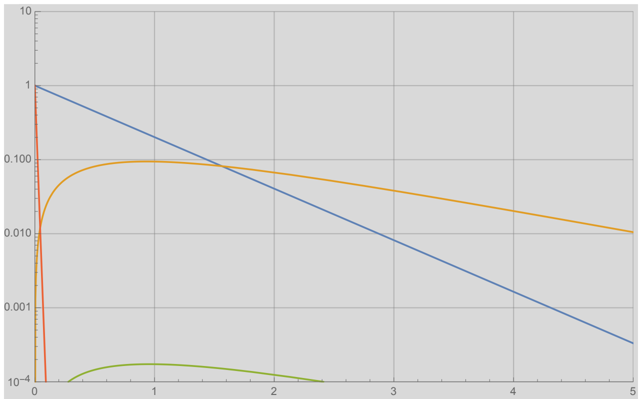
No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

Parameters:

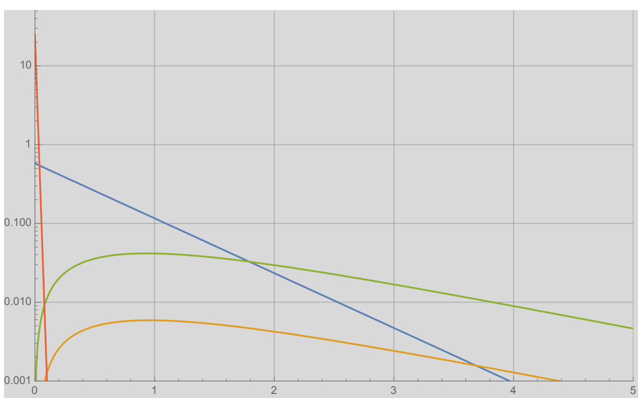
- $f_S = 0.25$
- $\tau_{128_S} = 0.010\ \mu s$
- $f_T = 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q = 0.11\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$
- $[N_2] = 5\ \text{ppm}$
- $[Xe] = \frac{1.1}{3.3}\ \text{ppm}$ (Dope *1*)
- $k_{EnT1} = 0.17 \times 5\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$
- $\tau_{149} = 5.1 \times \frac{1}{3}\ \mu\text{s}$
- $k_{EnT2} = 0.05 \times 5\ \text{ppm}^{-1}\ \mu\text{s}^{-1}$
- $\tau_{174} = 0.022\ \mu s$



Solution of State Equations

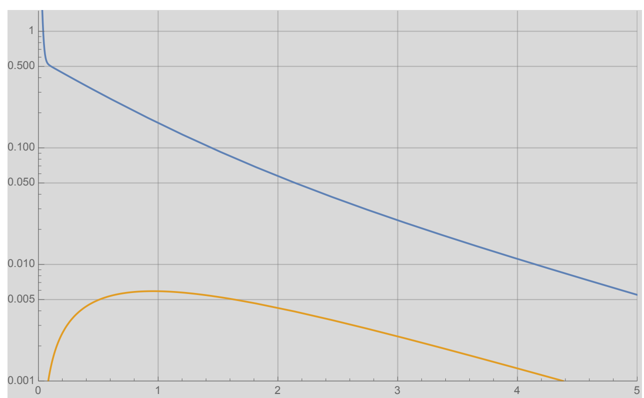
Dope 1

Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5
And
Decrease τ_{149} by (arbitrary) factor x$\frac{1}{3}$

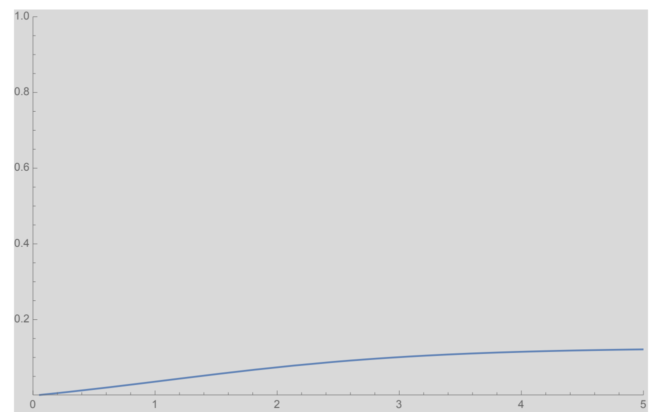


Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's

Note: ArXe >> Xe



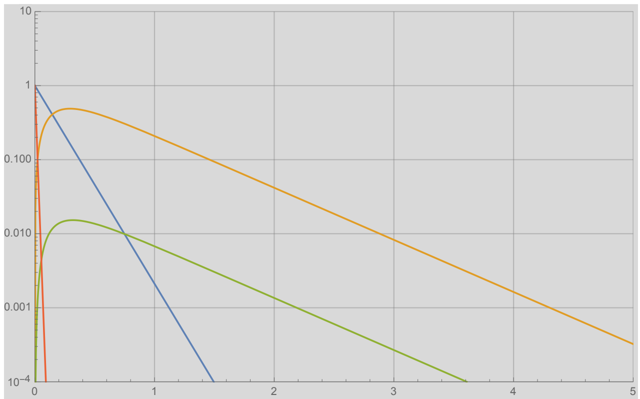
No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

Parameters:

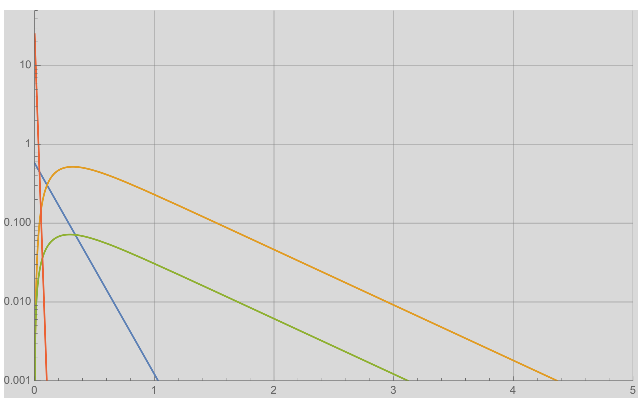
- $f_S \;=\; 0.25$
- $\tau_{128_S} \;=\; 0.010\ \mu s$
- $f_T \;=\; 0.75$
- $\tau_{128_T} = 1.3\ \mu s$
- $k_Q \;=\; 0.11\ \mathrm{ppm}^{-1}\ \mu s^{-1}$
- $[N_2] \;=\; 5\ \mathrm{ppm}$
- $[Xe] \;=\; \frac{18.8}{3.3}\ \mathrm{ppm}$ (Dope 1)
- $k_{EnT1} \;=\; 0.17 \times 5\ \mathrm{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{149} = = 5.1\ \mu s$
- $k_{EnT2} \;=\; 0.05 \times 5\ \mathrm{ppm}^{-1}\ \mu s^{-1}$
- $\tau_{174} \;=\; 0.022\ \mu s$



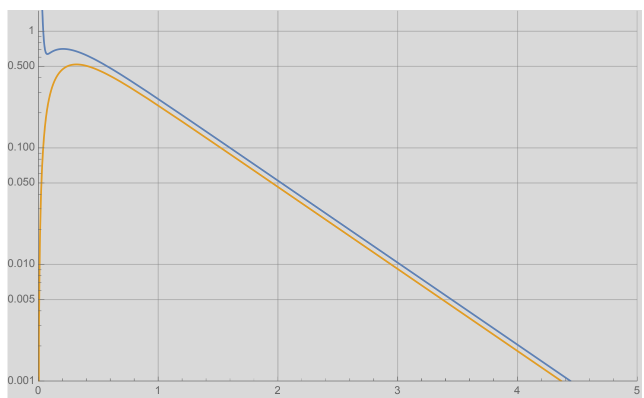
Solution of State Equations

Dope 5

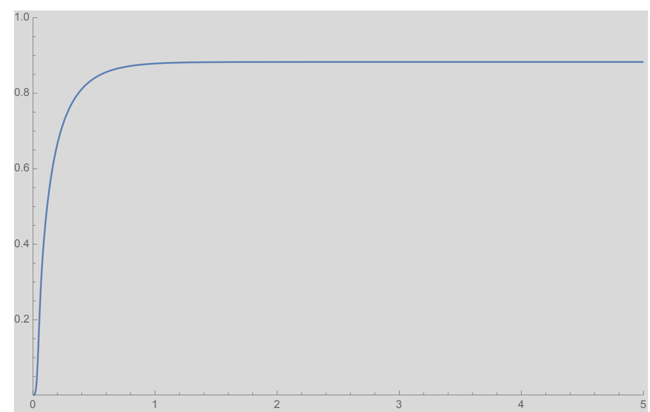
Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5



Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's



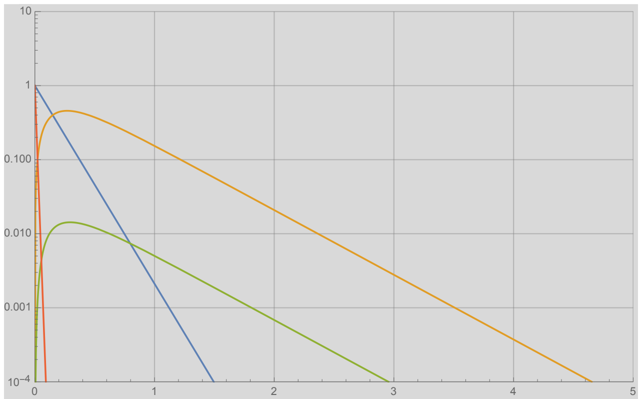
No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution

Parameters:

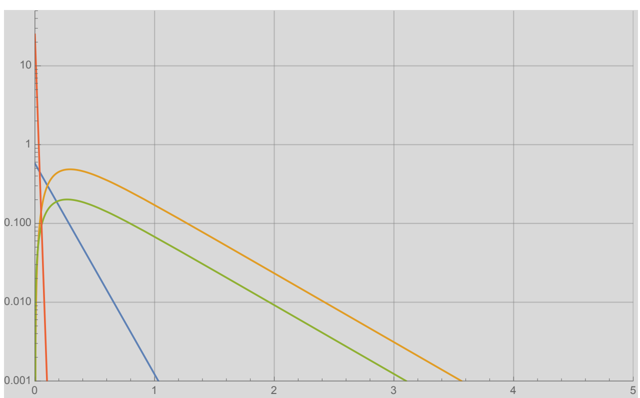
- $f_S \; = \; 0.25$
- $\tau_{128_S} \; = \; 0.010 \; \mu s$
- $f_T \; = \; 0.75$
- $\tau_{128_T} = 1.3 \; \mu s$
- $k_Q \; = \; 0.11 \text{ ppm}^{-1} \; \mu \text{s}^{-1}$
- $[N_2] \; = \; 5 \text{ ppm}$
- $[Xe] \; = \; \frac{18.8}{3.3} \text{ ppm}$ (Dope 1)
- $k_{EnT1} \; = \; 0.17 \times 5 \text{ ppm}^{-1} \; \mu \text{s}^{-1}$
- $\tau_{149} \; = 5.1 \times \frac{1}{3} \; \mu \text{s}$
- $k_{EnT2} \; = \; 0.05 \times 5 \text{ ppm}^{-1} \; \mu s^{-1}$
- $\tau_{174} \; = \; 0.022 \; \mu s$



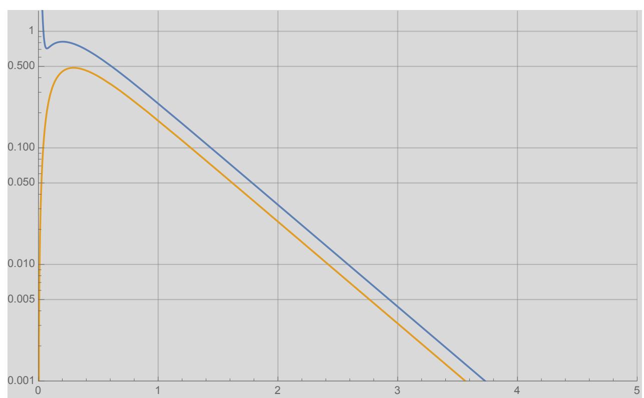
Solution of State Equations

Dope 5

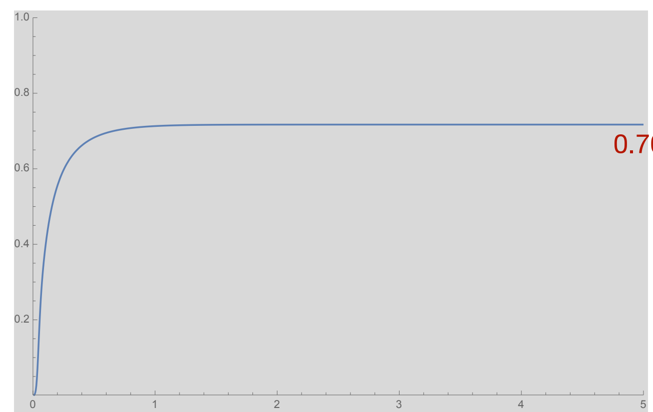
Increase k_{EnT1} and k_{EnT2} by (arbitrary) factor x5
And
Decrease τ_{149} by (arbitrary) factor x$\frac{1}{3}$



Ar_S, Ar_T, ArXe, Xe Scintillation Light Time Distribution Fcn's



No Quartz (Ar_S, Ar_T+ArXe+Xe) & **Quartz** (Xe)
detectable Light Time Distribution



Quartz (Xe) / No Quartz (Ar_T+ArXe+Xe) Ratio
detectable Light Time Distribution