# Proposal for ENDF formats that describe emission of post-fission β-delayed photons

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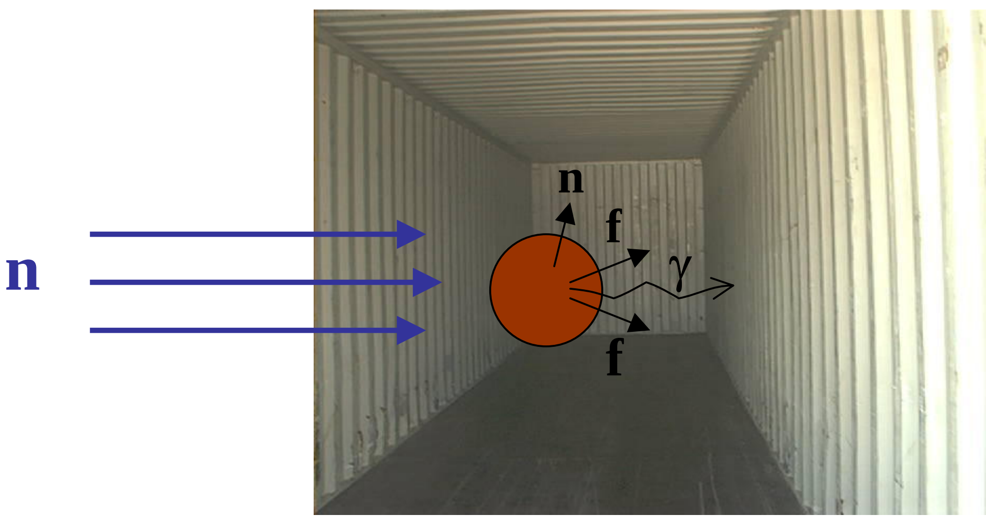
# Why delayed γ's from fission?

Homeland security: Detection of fissile material in sea-going cargo containers via detection of beta-delayed gamma-rays.

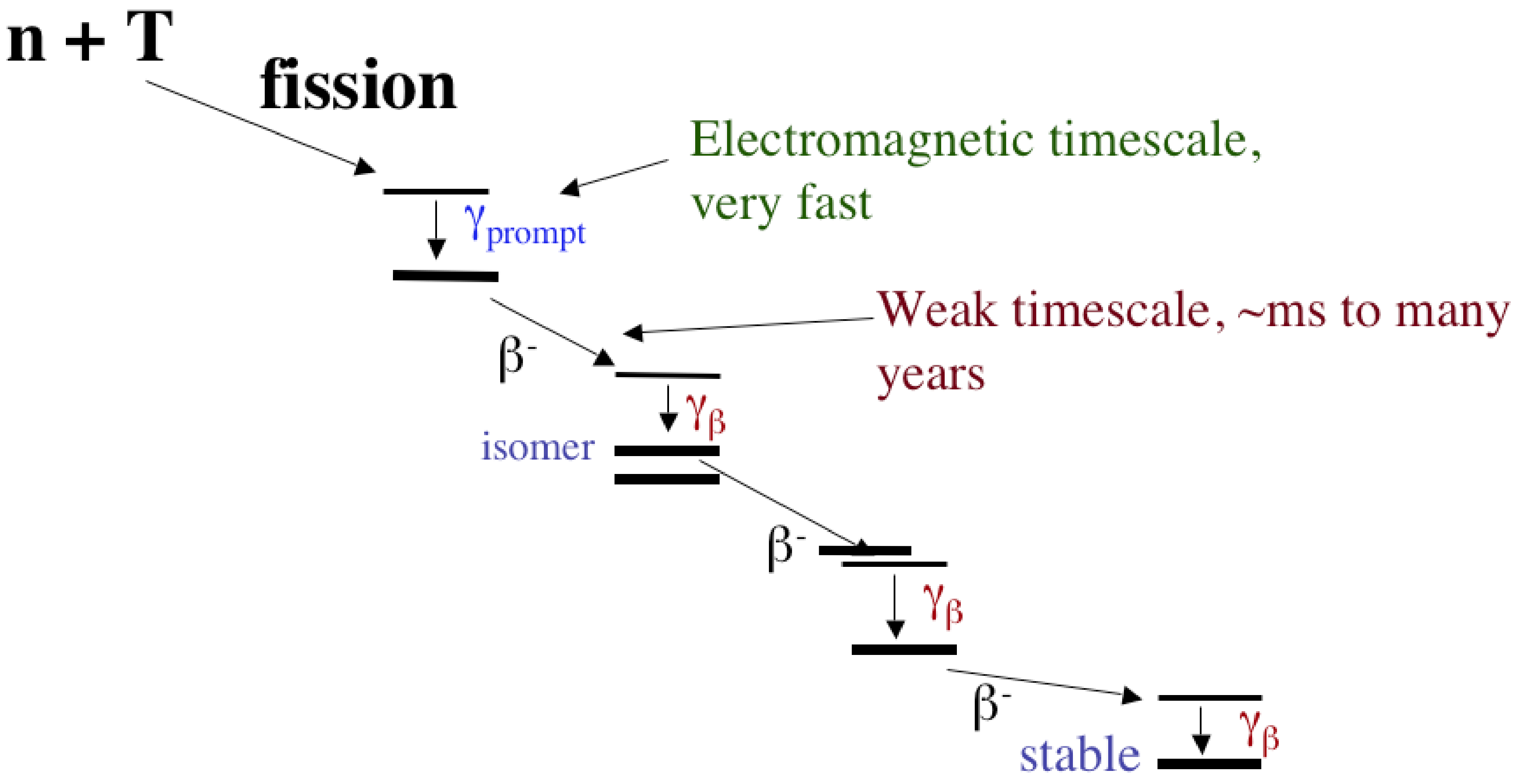



Cargo container, ~8'x8'x20'

Weight limit implies $\rho \leq 0.5$ g/cc

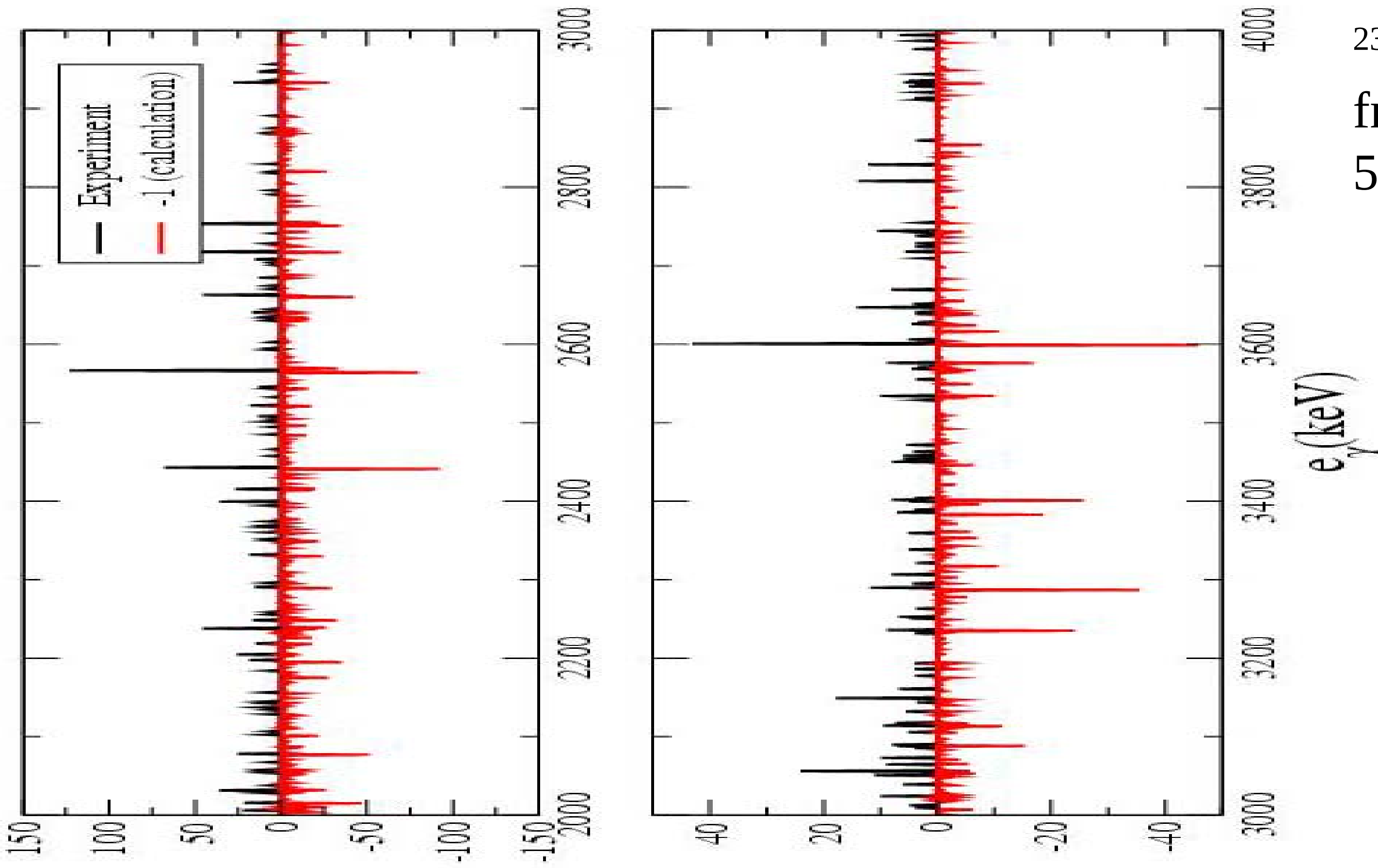
Assume active neutron interrogation techniques that rely on detection of post-fission β-delayed γ-rays.

# Delayed γ's have huge range of timescales




Long cascade ensures many timescales for individual gammas

# With keV resolution, see many γ's




$^{235}U(n_{th},f)$
from NIM A,
521, 608 (2004)

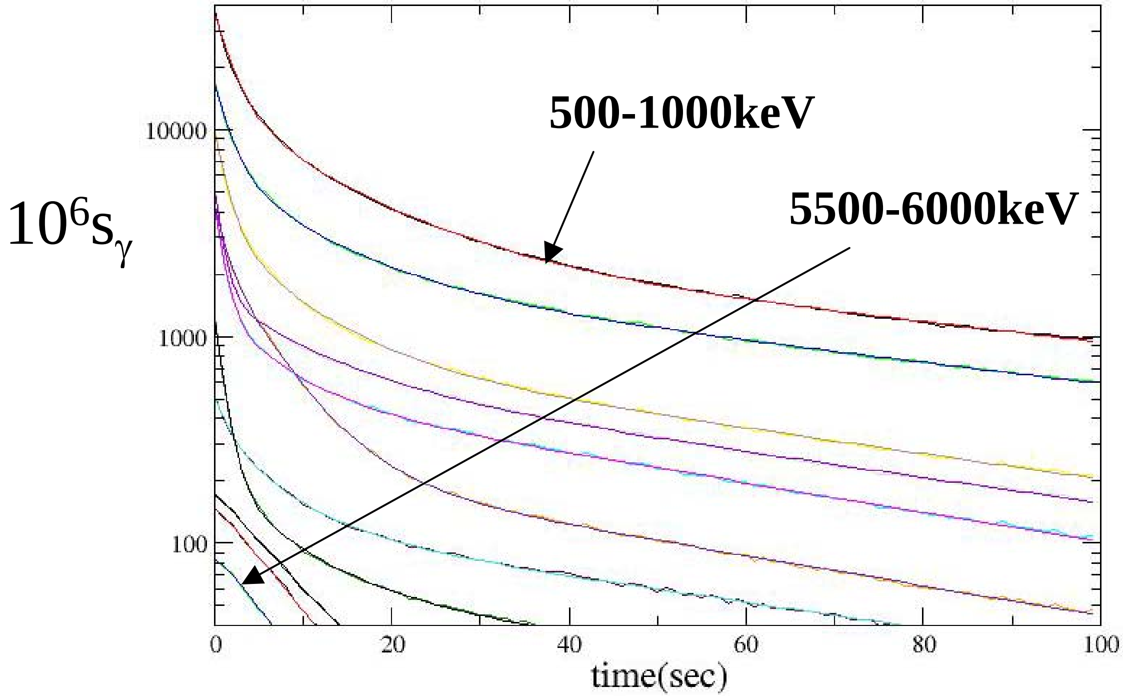
Can approximate γ spectrum w/ continuous representation only w/ dramatic loss in resolution

# Define γ source function

$$s_\gamma(E,E_\gamma,t) \equiv \frac{d^2 n_\gamma}{dt\,dE_\gamma}(E,E_\gamma,t).$$

= probability per unit time per unit energy after fission event, photon is emitted at time *t* with energy $\varepsilon_\gamma$

There are different ways to represent $s_\gamma$. One is similar to the way delayed neutrons are represented (coarse energy bins):




jagged lines - Monte Carlo
smooth lines - fit

# Discrete Representation

$$s_\gamma(E,E_\gamma,t) = \sum_{i=1}^{NG} \delta(E_\gamma - E_i)\, y_i(E)\, T_i(t).$$

**Discrete Representation (LO=1)**

The following quantities are defined:

| | |
|---|---|
| **NG** | The number of discrete photons. |
| **NR, NP, $t_{int}$** | Standard TAB1 parameters. |
| **$T_i(t)$** | Time dependence of the $i^{th}$ photon's multiplicity ($sec^{-1}$). |

The structure of the time dependence data block is:

[MAT, 1, 460/ ZA, AWR, LO=1, 0, NG, 0 ] HEAD
[MAT, 1, 460/ 0.0, 0.0, 1, 0, NR, NP/$t_{int}$/$T_1(t)$] TAB1
[MAT, 1, 460/ 0.0, 0.0, 2, 0, NR, NP/$t_{int}$/$T_2(t)$] TAB1
…
[MAT, 1, 460/ 0.0, 0.0, NG, 0, NR, NP/$t_{int}$/$T_{NG}(t)$] TAB1
[MAT, 1, 0/ 0.0, 0.0, 0, 0, 0, 0] SEND

"Complete," but huge datasets

# Continuous Representation

$$s_\gamma(E,E_\gamma,t) = \sum_{i=1}^{NNF} y_i(E)\, f_i(E\leftarrow E_\gamma)\, \lambda_i \exp(-t\lambda_i).$$

**Continuous Representation (LO=2)**

The following quantities are defined:

**NNF** The number of precursor families considered.

$\lambda_i$ Decay constant ($sec^{-1}$) for the $i^{th}$ precursor.

The structure of this data block is:

[MAT, 1, 460/ ZA, AWR, LO=2, 0, 0, 0] HEAD

[MAT, 1, 460/ 0.0, 0.0, 0, 0, NNF, 0/$\lambda_1$, $\lambda_2$, … $\lambda_{NNF}$] LIST

[MAT, 1, 0/ 0.0, 0.0, 0, 0, 0, 0] SEND

Don’t resolve individual γ’s, but format like delayed n data