Total Absorption Spectroscopy for Nuclear Beta decays

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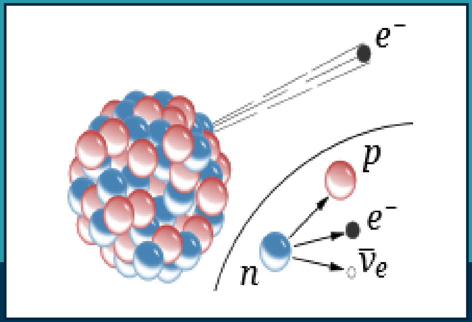
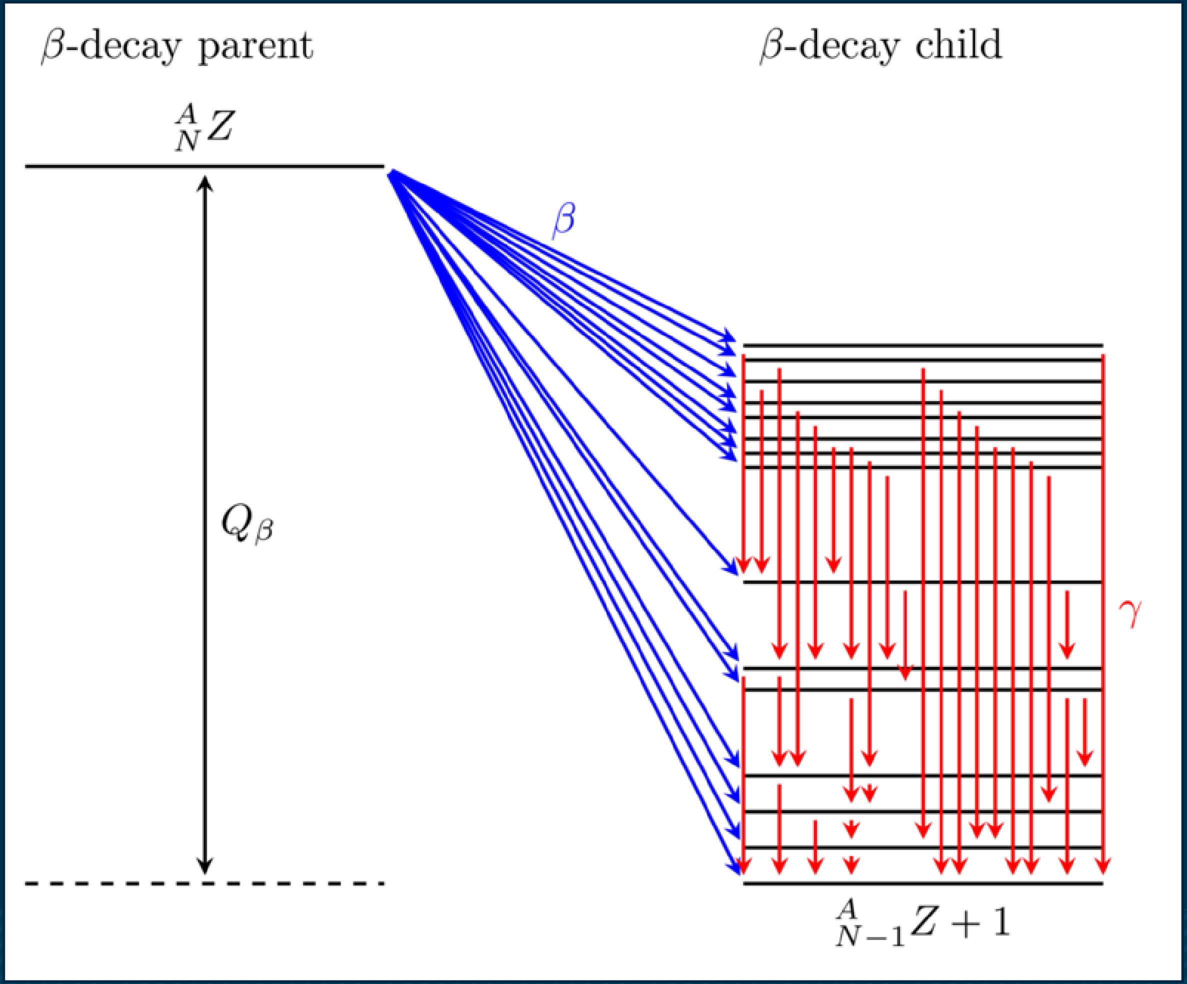
NNPSS 2026, UW, Seattle

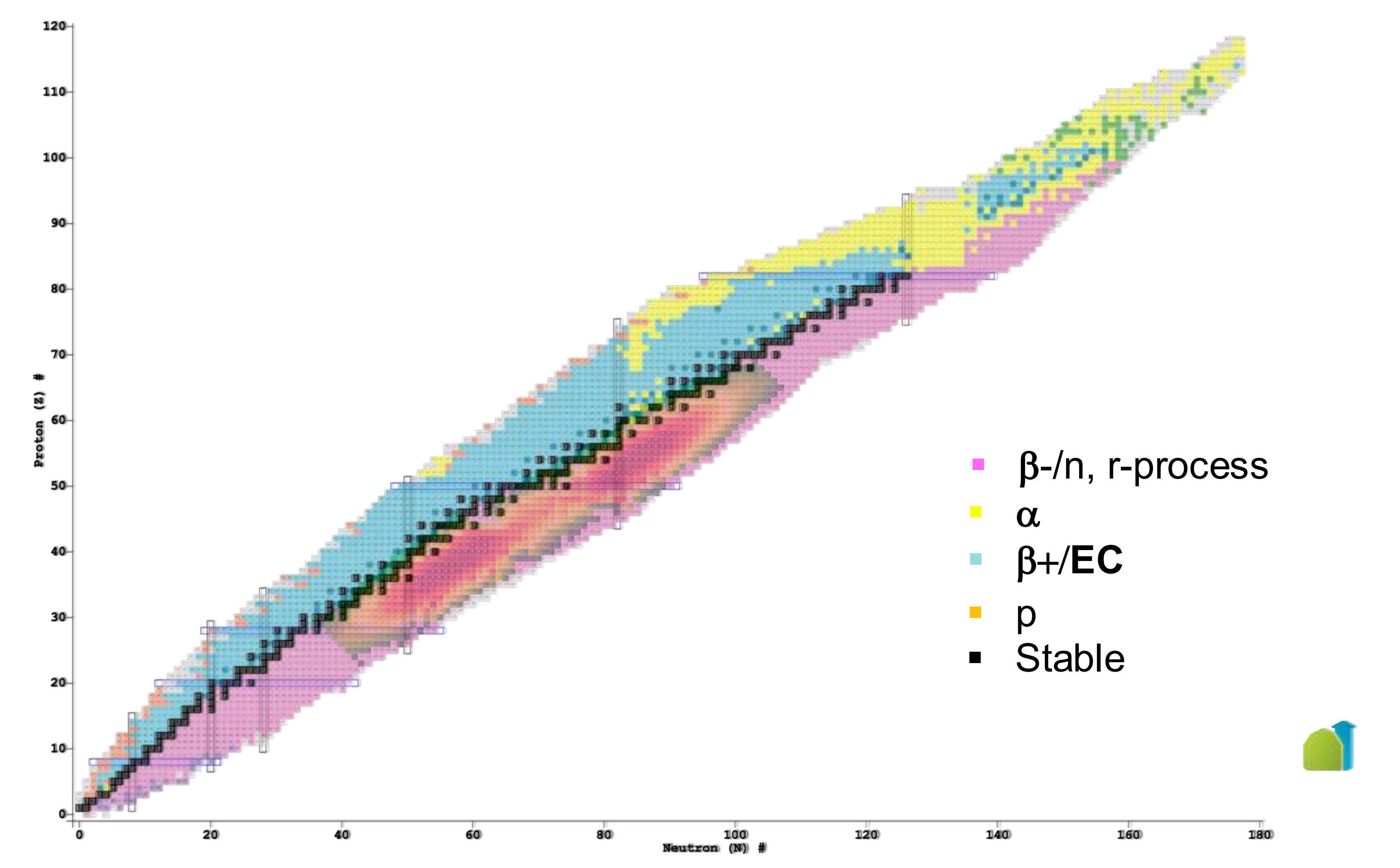
β-Decay in a Nucleus (β -)





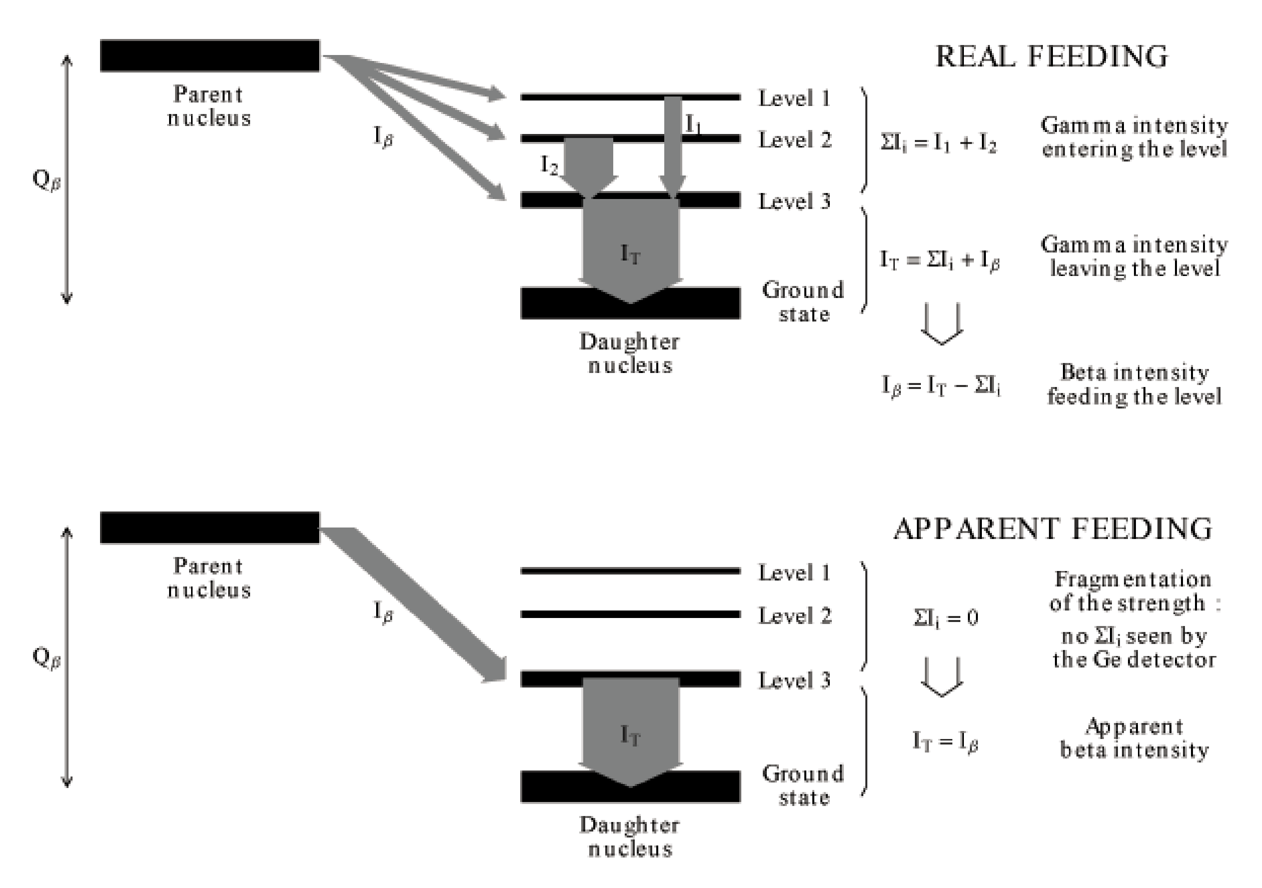
- In many cases, the daughter nuclei is produced is in an excited state
- The excited daughter nuclei produces a series of gamma rays and conversion electrons as it deexcites
- Total energy released is capped by the Q_β value
- Ground state to Ground State:
  - $Q_\beta = \big(M(Z,N) - M(Z+1, N-1)\big)c^2$
- Energy shared among:
  - Anti-neutrino
  - Electrons
  - Nuclear recoil
  - Gamma rays (from excited daughter nuclei)

β-decays, β-n decays and U235 Fission-Yields



Screenshots from : https://www.nndc.bnl.gov/nudat3/

Pandemonium Effect



Majority of the current nuclear data was taken with low-efficiency detectors like HPGe.

With 1-5% efficiency, they miss a lot of weak gamma-ray transitions.

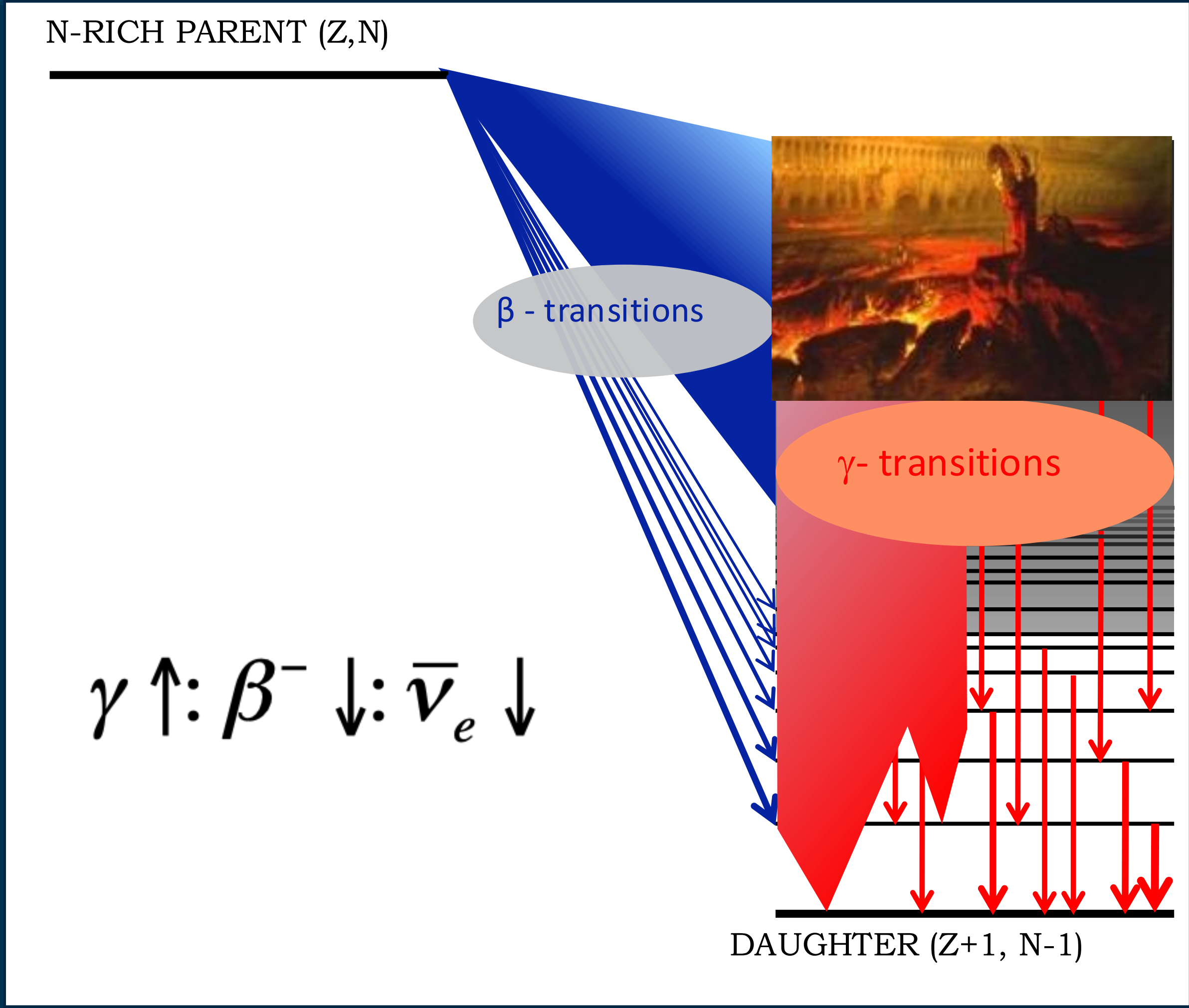
"Bad Low-light performance"

Low-efficiency combined with weak gamma transitions at higher levels implies:

- Misinterpreting many multi–gamma decays as direct feeding to lower levels.
- More energy to leptons and less to gammas in decay models
- Level feeding close to the Q value is underestimated or completely missed.
- Models based in this data produce wrong predictions

https://commons.wikimedia.org/wiki/

How to avoid Pandemonium Effect? Detect Everything



Use High-Efficiency Detectors like the Total Absorption Spectrometers(TAS).

The *goal* is to efficiently detect all emitted γ-rays and betas.

This typically increases the beta feeding to higher energy levels

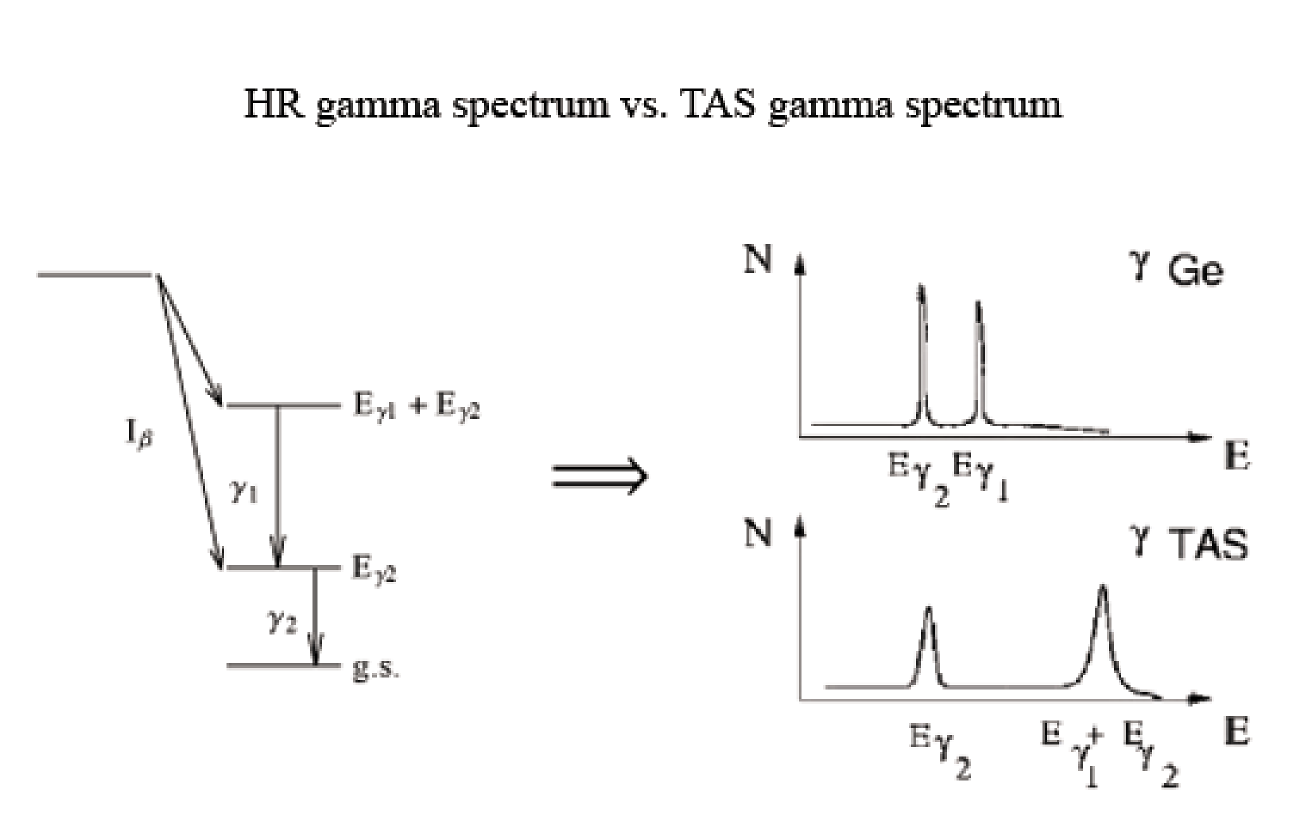
Accounting for the gammas from the higher levels reduces the average energy for the e- and anti-neutrino and anti-neutrino anomaly.

Probe Nuclear Level density and gamma strength functions up to the Q value.

Bonus: Half-life values

Image Credit: B.C. Rasco and https://commons.wikimedia.org/wiki/File:Schematic_diagram_showing_the_Pandemonium_effect.png

Total Absorption Spectroscopy



- With a germanium detector (Ge), the energy peaks corresponding to individual gamma transitions
- TAS detector gives a spectrum of the levels populated in the decay.

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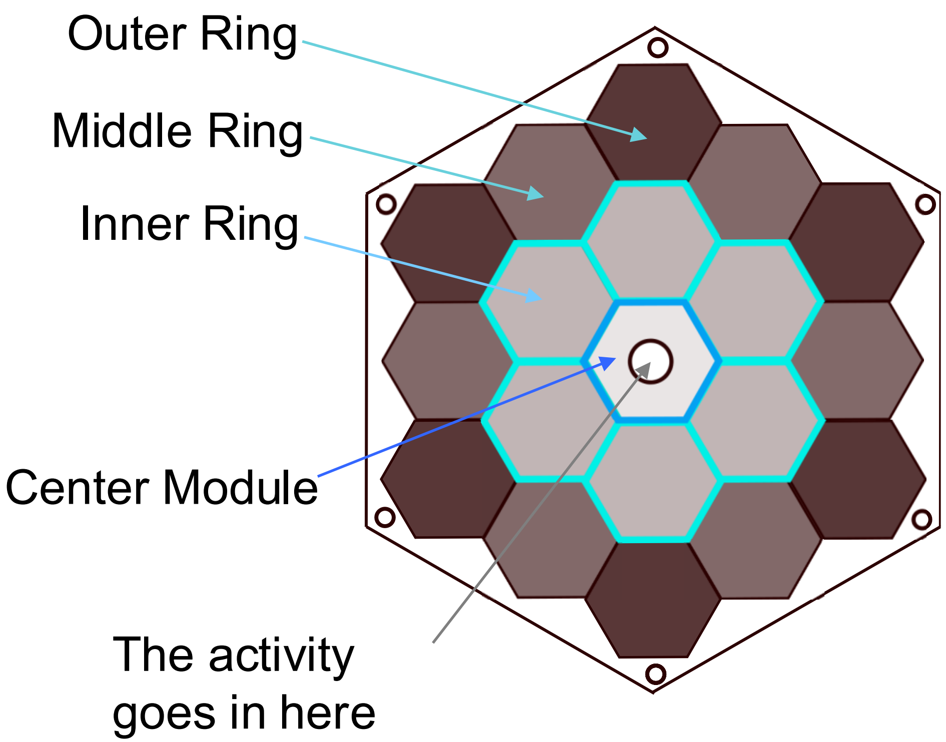
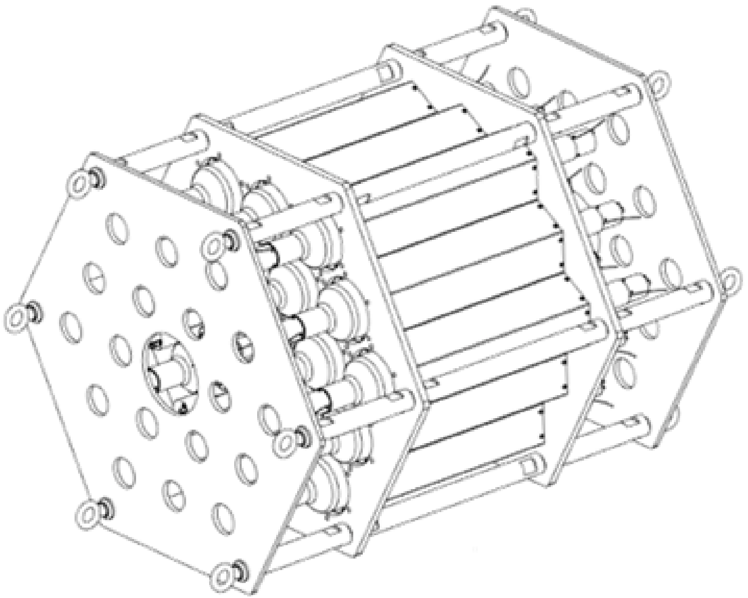
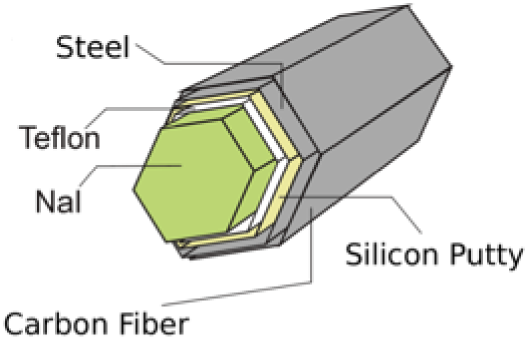
The Modular Total Absorption Spectrometer - MTAS (ORNL)



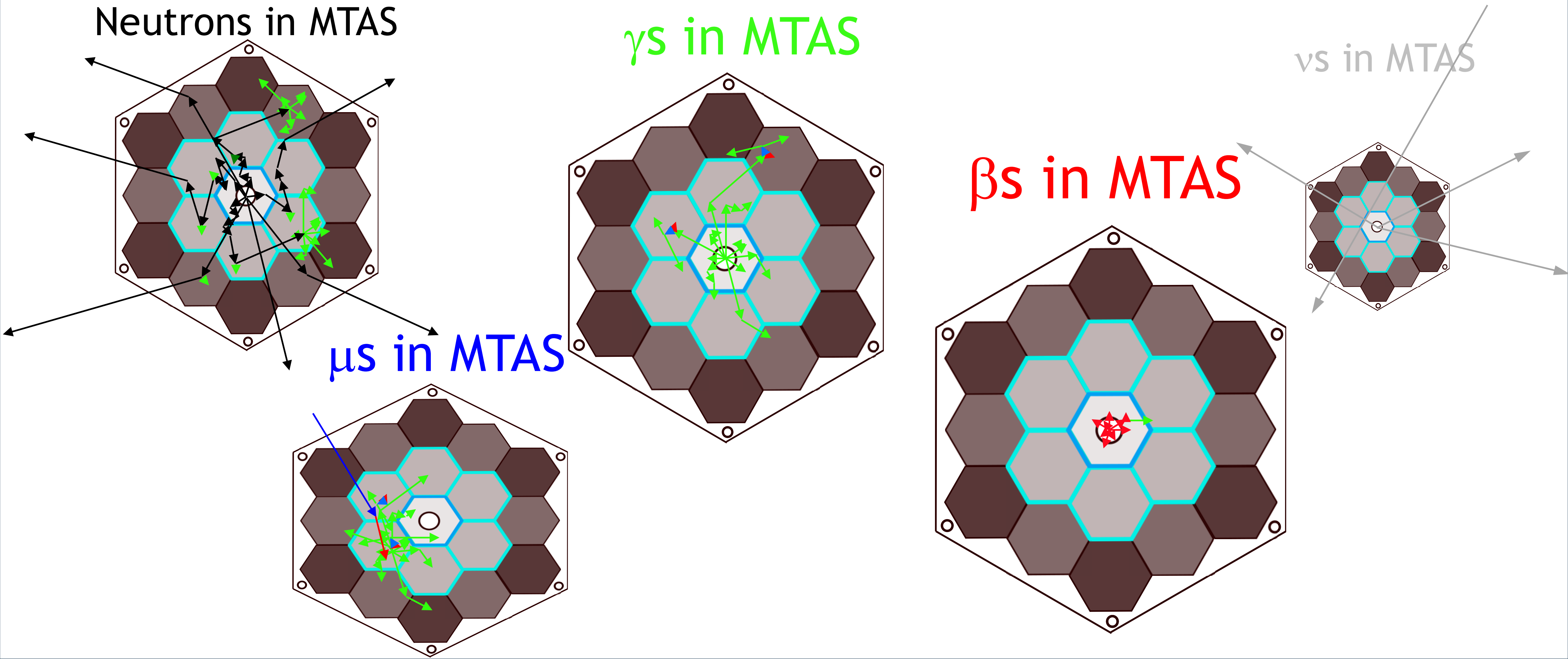




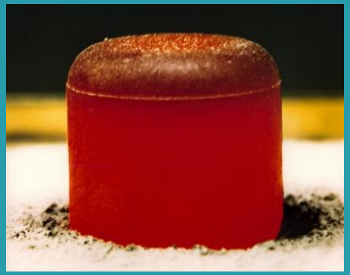
- 1 ton of NaI
- 19 NaI(Tl) crystals and 48 PMTs
- Total gamma efficiency : 98-99%
- *Good Low-light performance*

Karny, *et al.*, NIM A **836** (2016) 83–90
Wolińska-Cichocka, *et al.*, Nuclear Data Sheets **120** (2013) 22
Rasco, et al., NIM A **788** (2015) 137-145

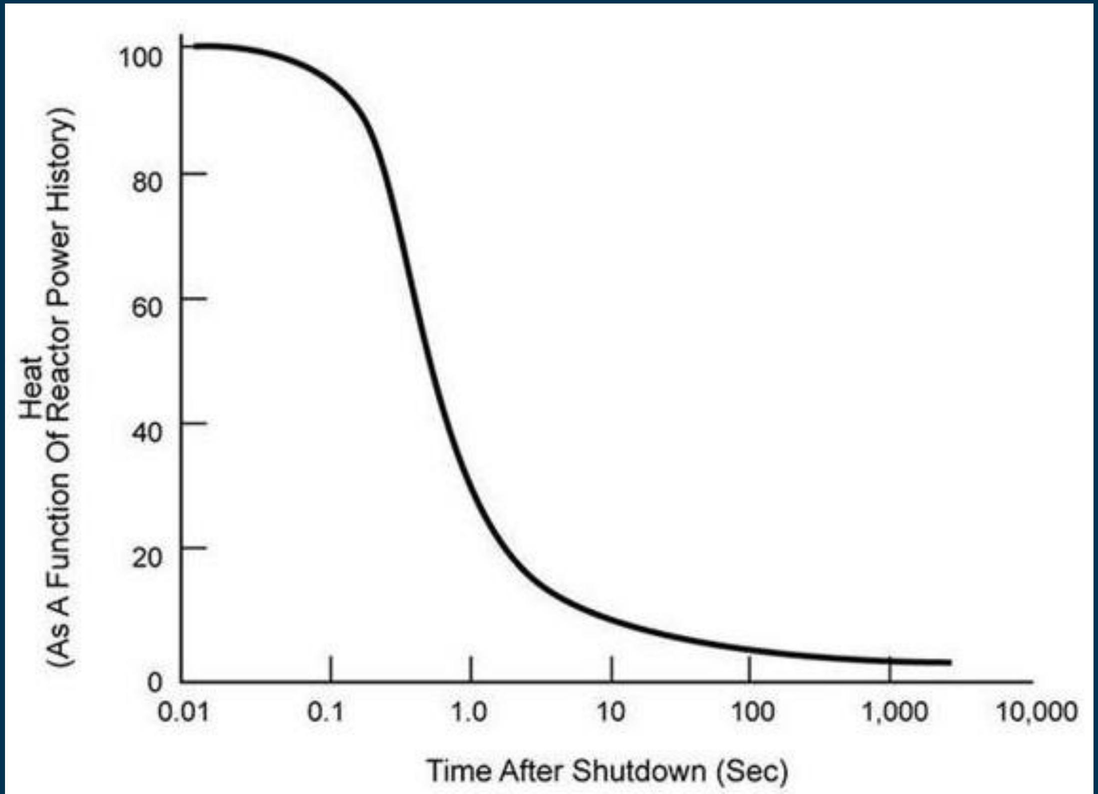
Total?



Decay heat in r-process and reactors



Plutonium-238 glowing due to decay heat



- **Decay Heat:** Thermal Energy produced by the unstable nuclei when they decay.
- Heats up the surrounding matter in r-process as well as the core of a nuclear reactor after shutdown
- Increases the average neutron kinetic energy
- Can cause damage to the reactor and even a meltdown
- How much and where that heat is deposited depends on the energy carried by the different decay products.
- Prediction needs good decay data where TAS measurements are important.

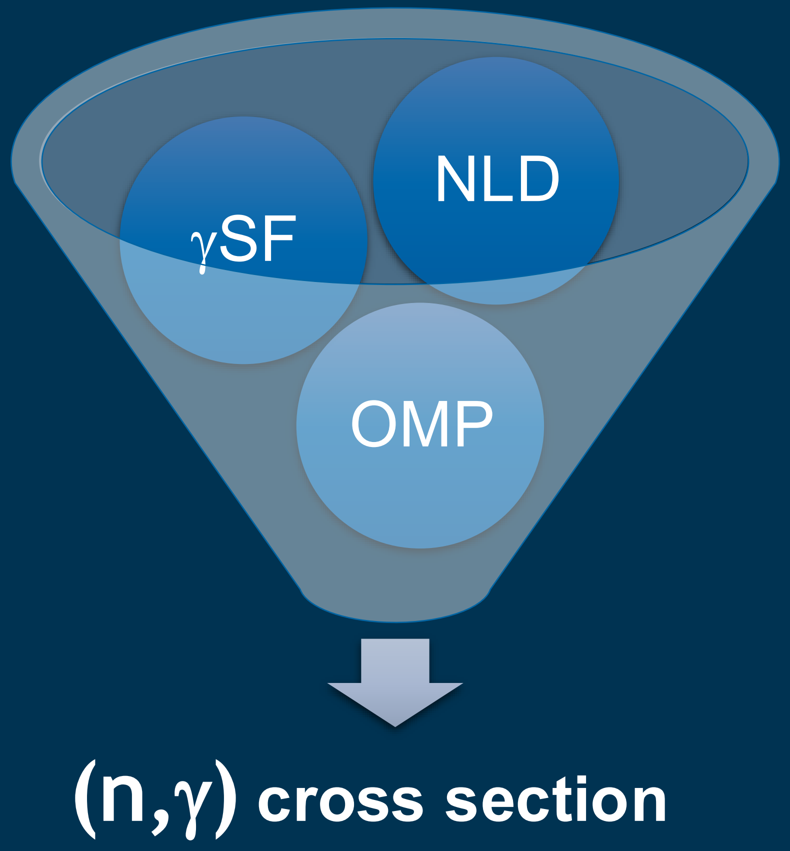
https://forums.kleien.com/forums/topic/128221-nuclear-decay-heat/

(n,γ) cross section without making neutron targets

Models for (n,γ) cross section such as, *Hauser-Feshbach* need three fundamental nuclear properties to predict cross sections:

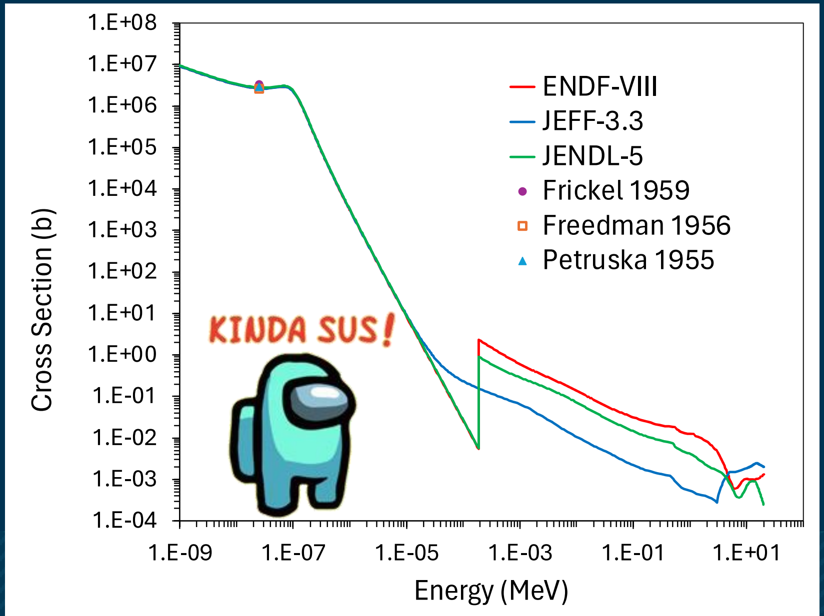
- Optical Model Potential (OMP)
- Nuclear Level Density (NLD)
- Gamma-ray Strength Function (γSF)

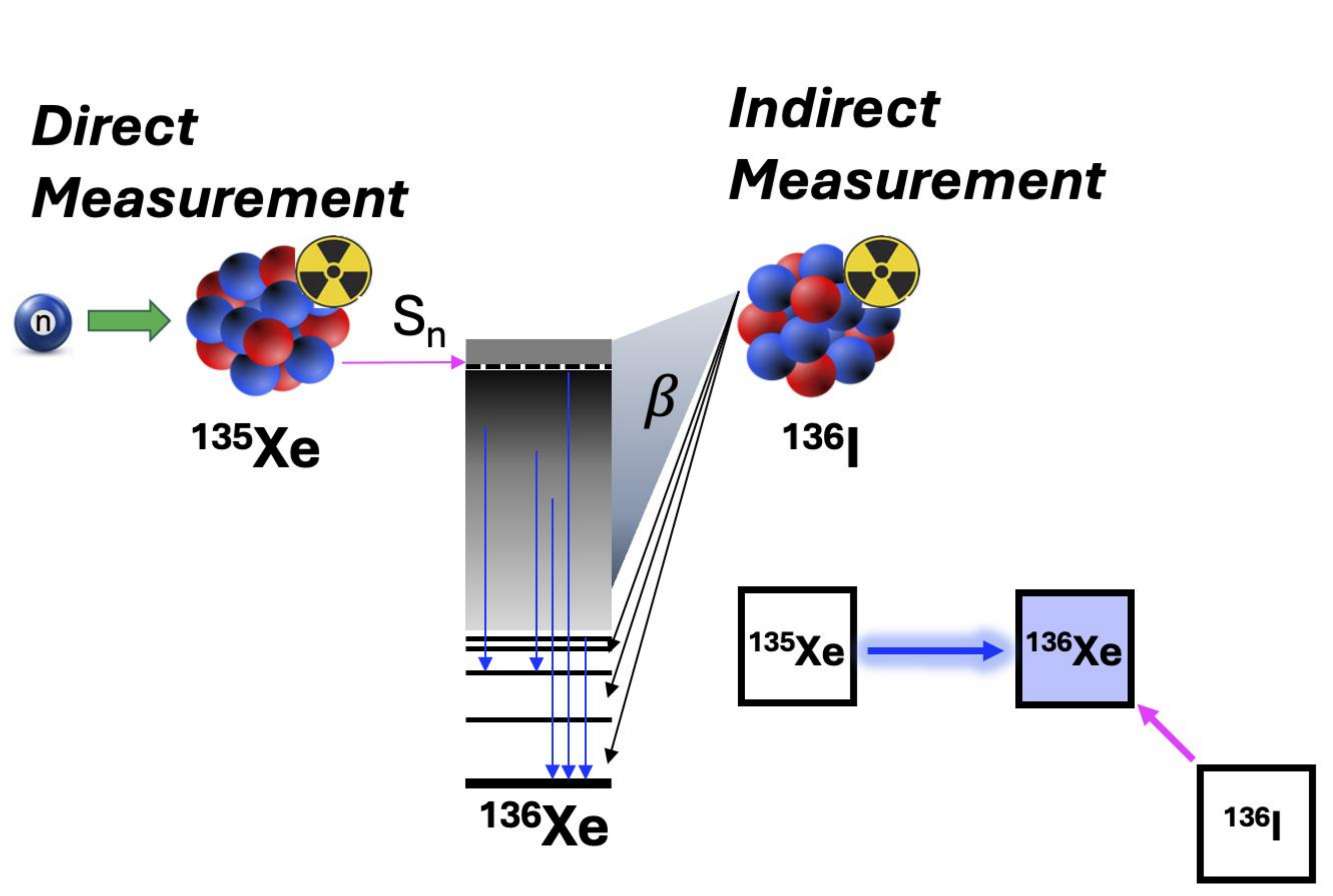
TAS measurements provide the NLD and γSF up to the Q_β which constrains the neutron burnup rate in r-process as well a rector cores at higher neutron energy.



Example : Xe135 (9.14 hours half-life)

- ^{135}Xe is a **well-known neutron poison** in nuclear reactors due to its unusually-large absorption cross section.
- However, the $^{135}Xe(n,g)$ cross section is famously unknown at energies higher than thermal.
- Infamous for its major contribution to the **Chernobyl disaster**





Thank You