Microscopic Investigation of the ^{57}Fe Gamma-ray Strength

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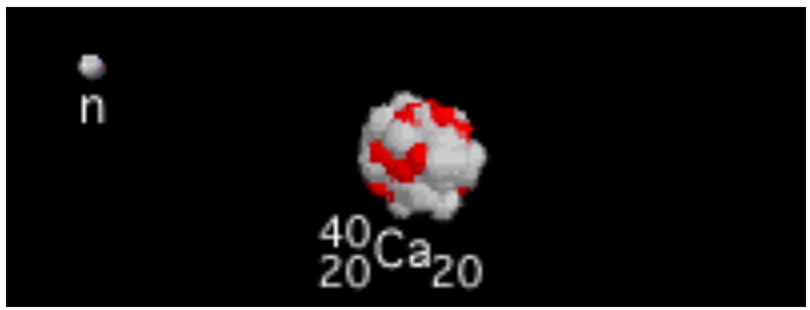

5th Workshop on Nuclear Level Density and Gamma Strength
Oslo, 18 – 22 May, 2015

Berkeley UNIVERSITY OF CALIFORNIA Nuclear Engineering

Collaboration

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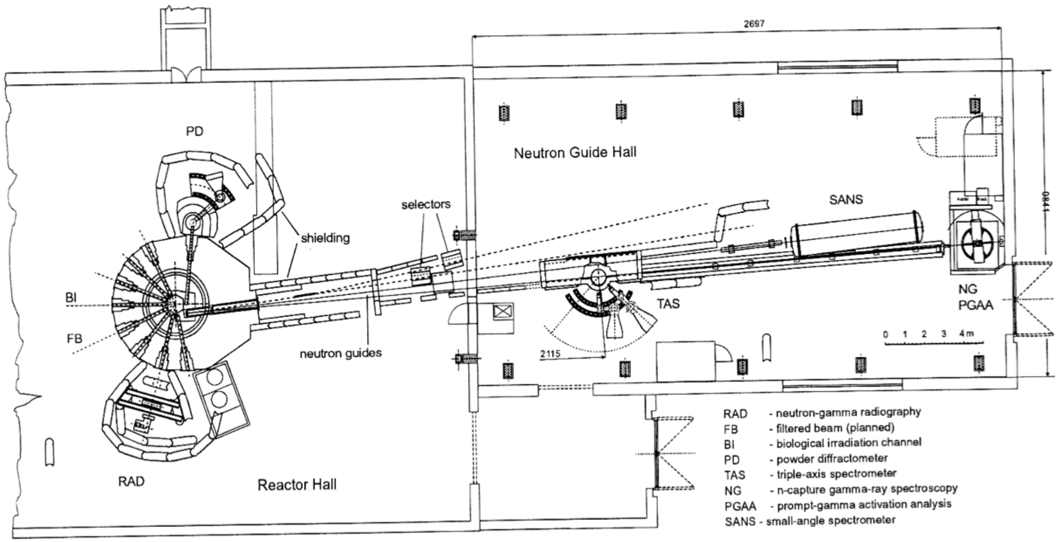
^{56}Fe(n,γ) Experimental Facilities



Budapest Reactor PGAA Measurements. Guided, curved neutron beam ≈30 m from the reactor wall.

HPGe: Compton suppressed γ-ray spectrum
Efficiency: <1% for E=0.5-6 MeV, <3% for 6-10 MeV.
Cold neutron flux: 1.2×10^{8} n·cm^{-2}s^{-1}.

^{56}Fe(n,γ), target enriched to 99.94% in ^{56}Fe

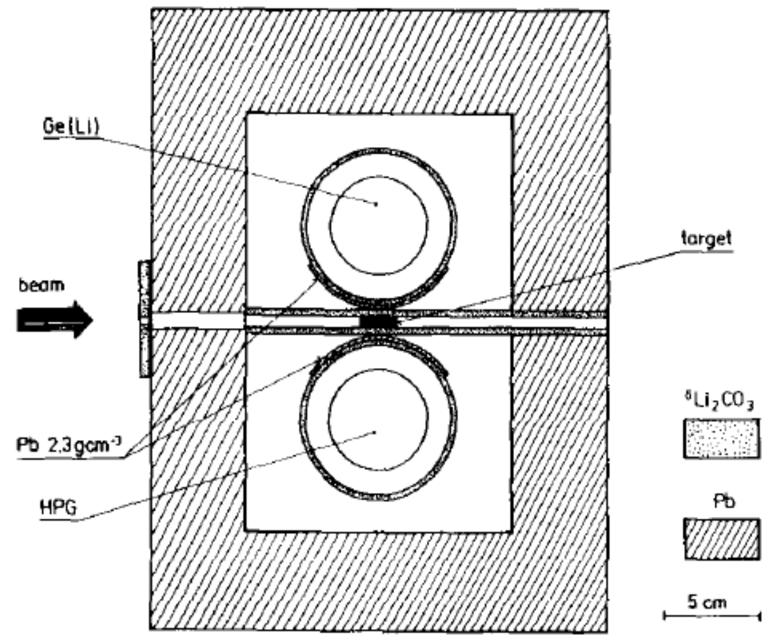
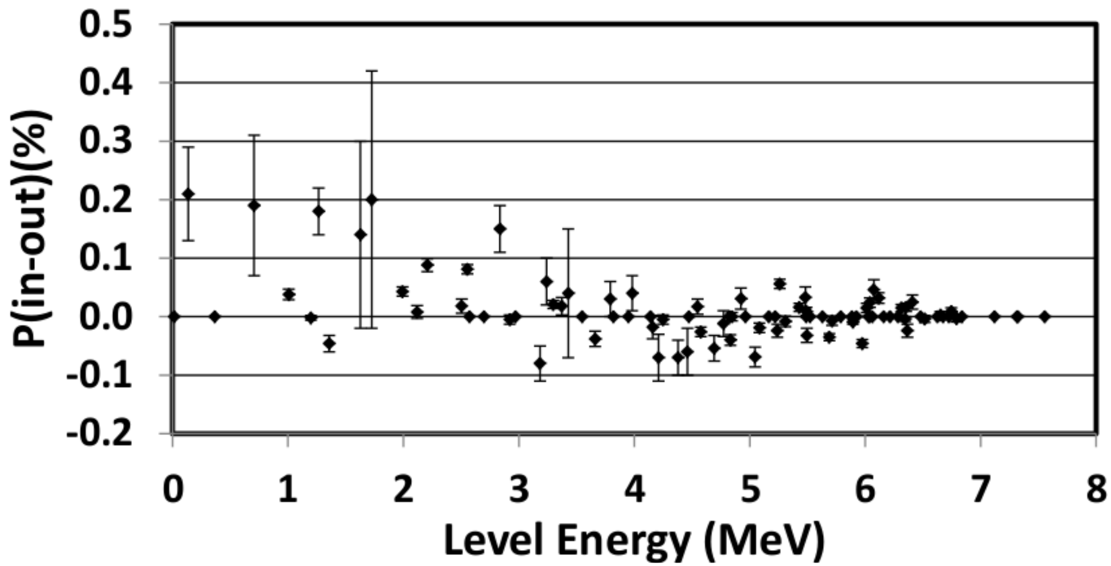


Fig. 1. The detector system and the shielding.

Rez (Prague) (n,$\gamma\gamma$) coincidence facility. Measured sum coincidence spectra with HPGe and Ge(Li) detectors.
Thermal flux: 2.8×10^{6} n·cm^{-2}s^{-1}.

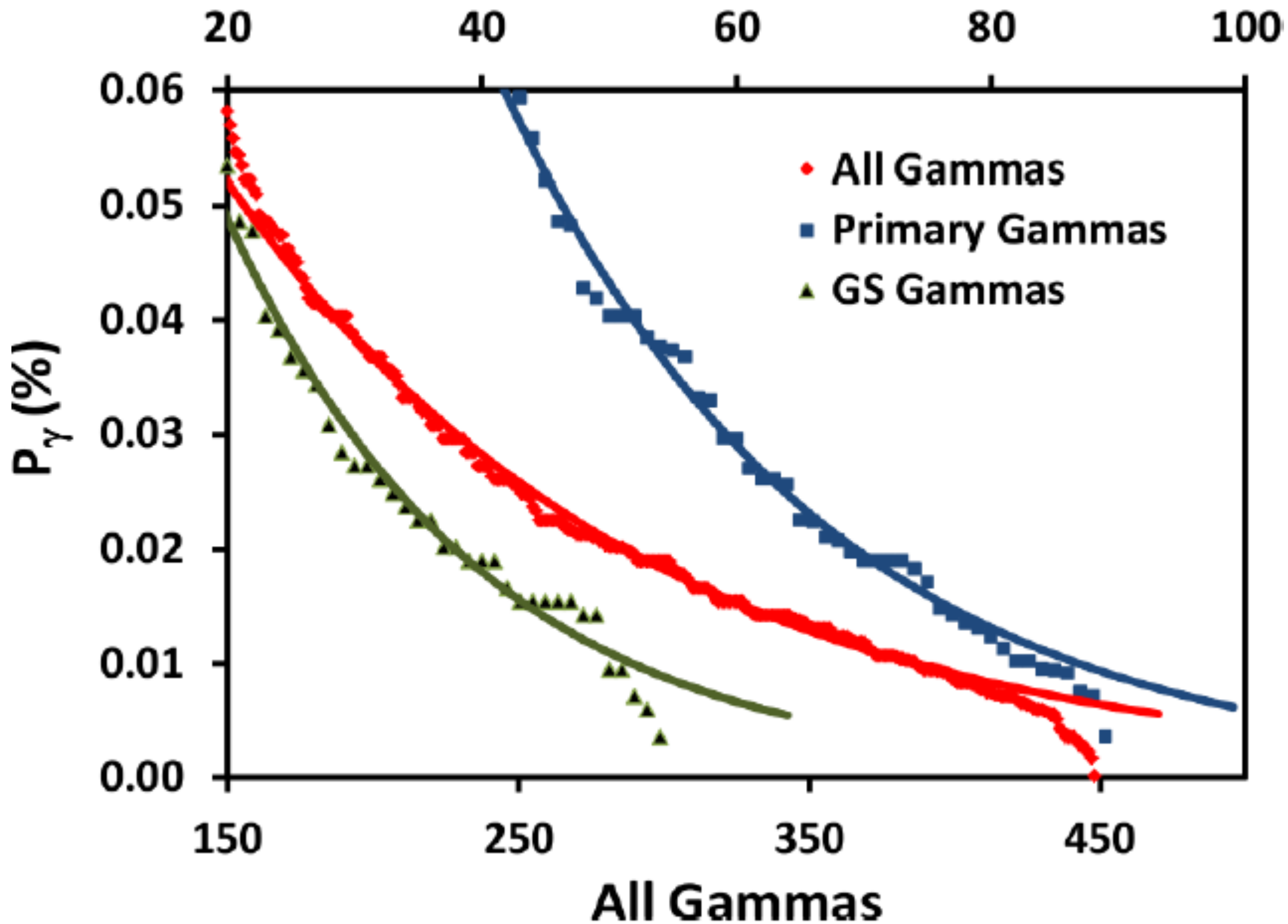
^{57}Fe Decay Scheme

- 449 γ-rays were placed populating 98 levels and the capture state in ^{57}Fe.
- 36 levels that were adopted in ENSDF could not be confirmed in this work including 32 levels previously assigned in earlier (n,γ) experiments.
- 37 new levels have been added in this work
- Decay scheme is nearly perfectly balanced with discrepancies of <0.2% through all levels.



Decay Scheme Completeness

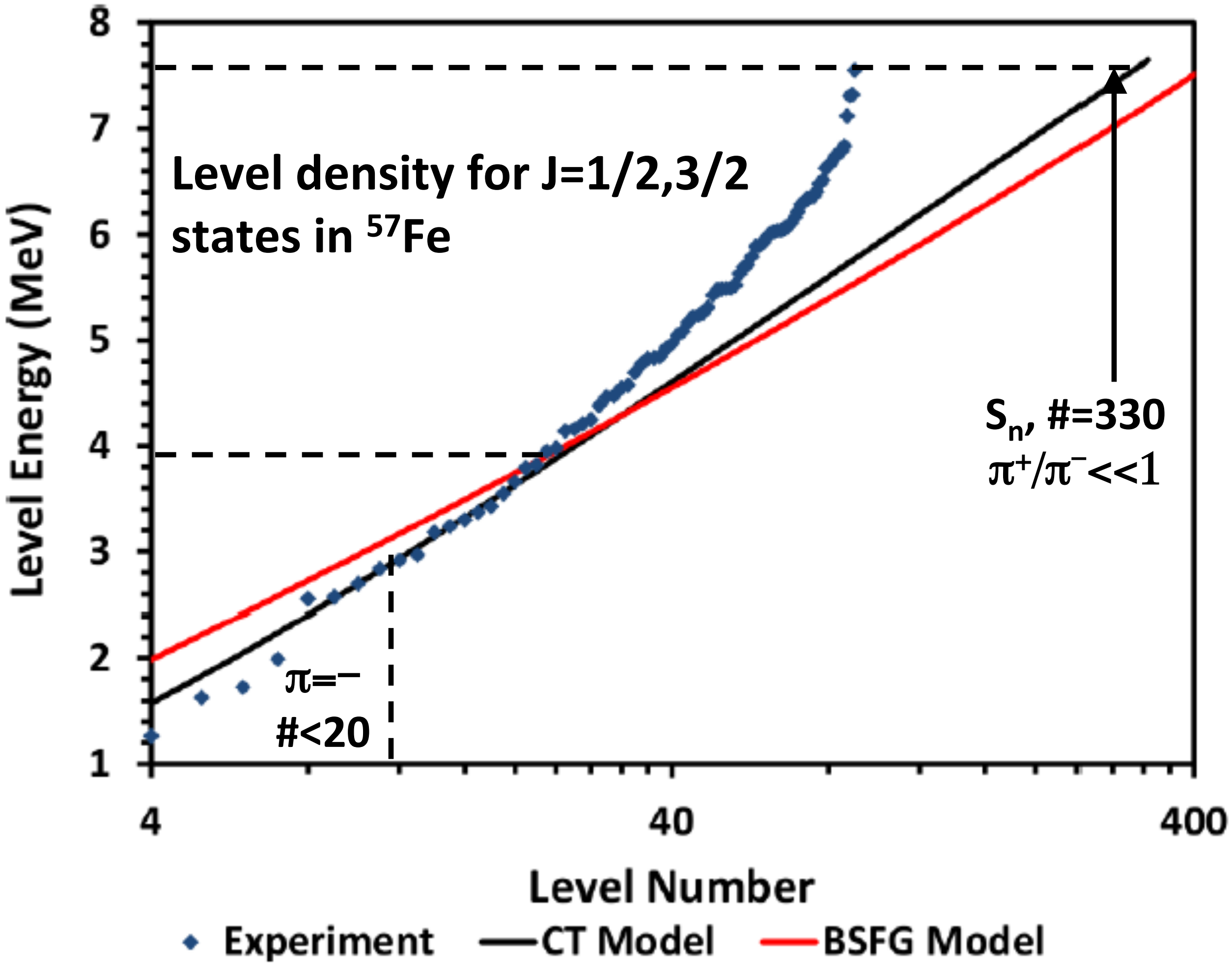
Distribution of γ-ray intensities falls off exponentially. Integration of exponential indicates that CS and GS γ-rays are 99.8% complete and total γ-ray intensity is 99% complete, consistent with observed $\Sigma P_{\gamma} E_{\gamma} / E_{SN} = 0.991$.



Intensity ordered plot of all, primary, and GS feeding γ-

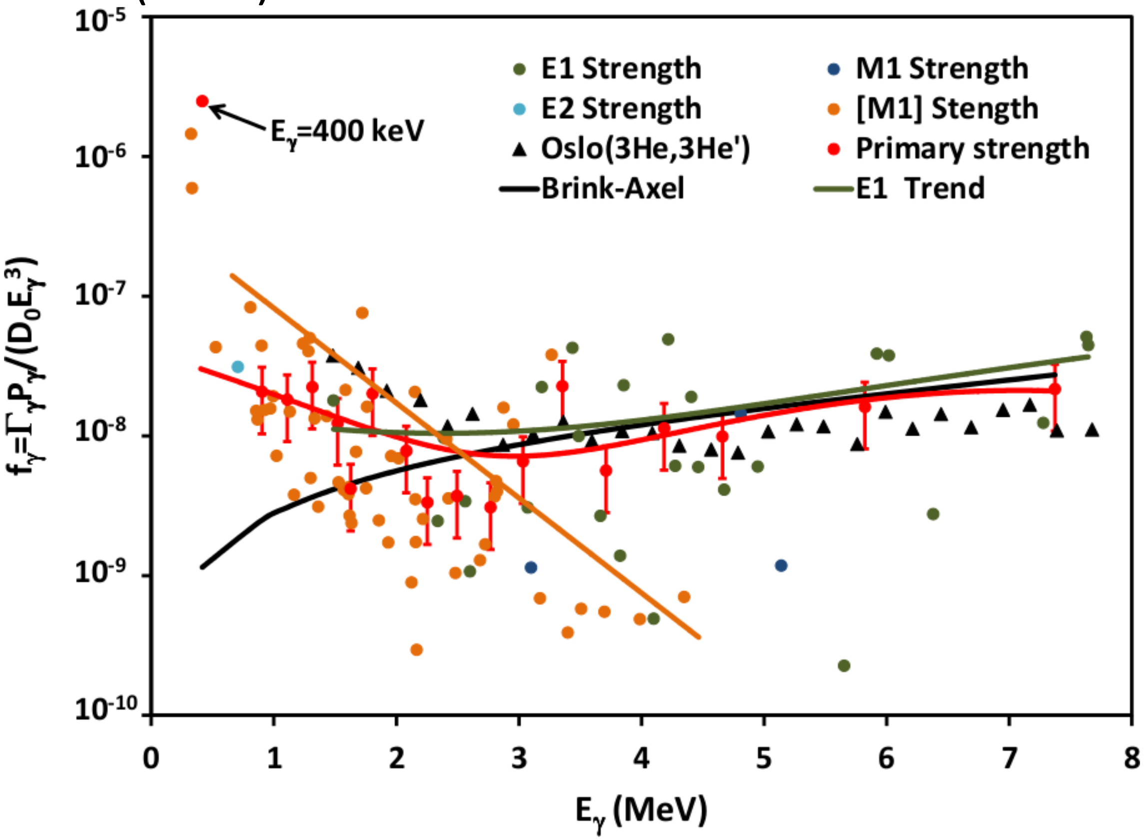
Level Density

Level density follows CT model up to 3.9 MeV. First π=+ state is at 2.9 MeV. If the π=+ states increase with the same exponential slope as π=− states, only ≈50 π=+ states are expected out of ≈330 total 1/2,3/2 states below S_n.



Primary γ-ray strengths

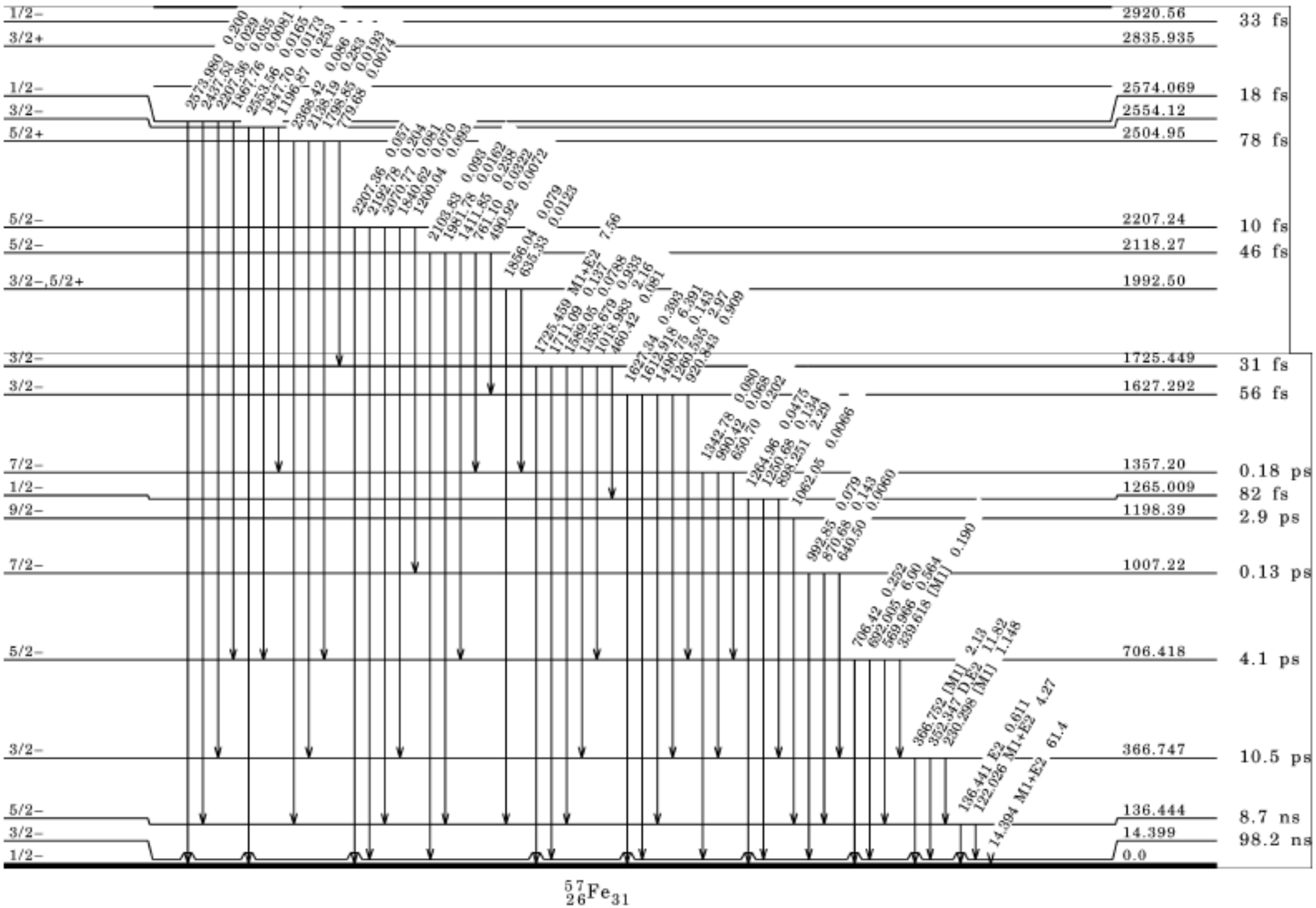
Individual primary γ-ray strengths are calculated by $f_\gamma(E)=\langle\Gamma_{\gamma 0}\rangle P_\gamma/(D_0 E_\gamma^3)$ where $\langle\Gamma_{\gamma 0}\rangle=1.85\pm0.50\ eV$ (RIPL) and $D_0=22.0\pm1.7\ keV$ (Atlas).



- E1 primary γ-ray strengths follow Brink-Axel.
- Low energy γ-ray strengths greatly exceed Brink-Axel and are likely M1*.
- (n,γ) photon strengths are consistent with binned Oslo (^{3}He,^{3}He') photon strengths.

*see B.A. Brown and A.C. Larson, PRL **113**, 252502 (2014).

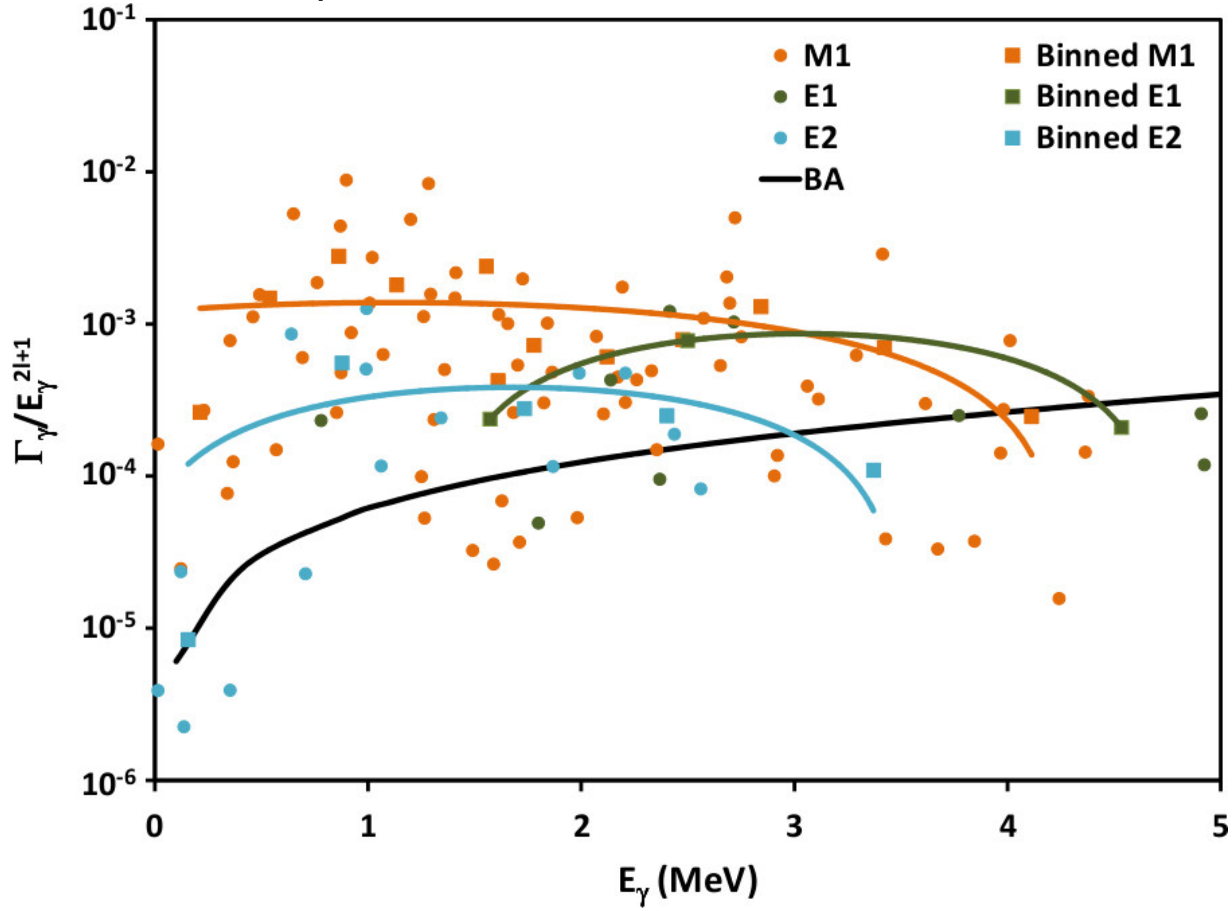
Secondary γ-ray strengths



The strengths for numerous secondary γ-rays can be determined where level half-lives are known.

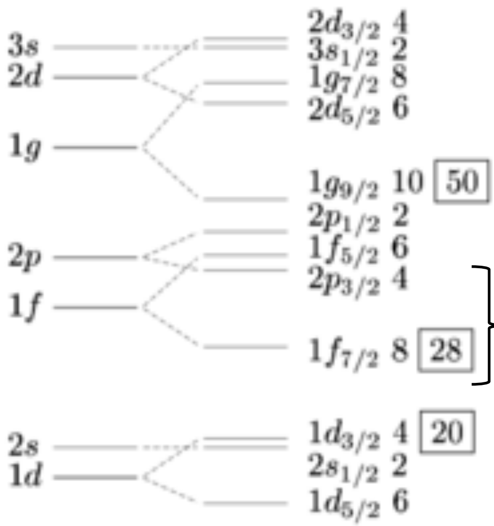
Secondary γ-ray strengths

The half-lives of most lower-lying levels in ^{57}Fe are known so the transition strengths of the secondary transitions can also be calculated



Low-energy, secondary M1, E1, and E2 γ-ray strengths exceed Brink-Axel predictions.

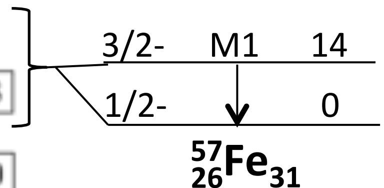
Low energy M1 γ-ray strength



Shell Model

Secondary γ-rays

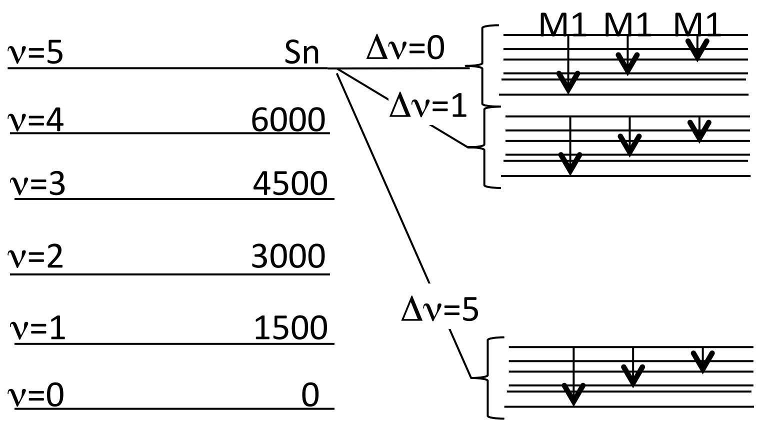
Low-lying levels in ^{57}Fe are built upon simple shell model configurations differing primarily by residual interactions. The γ-ray transitions between these states will be strong.



$$\pi(f_{7/2}^{-2}(0))_0\,\nu(p_{3/2}^2(0)\,p_{3/2}^1)_{3/2} + \pi(f_{7/2}^{-2}(2))_2\,\nu(p_{3/2}^2(0)\,p_{3/2}^1)_{3/2}$$

$$\pi(f_{7/2}^{-2}(0))_0\,\nu(p_{3/2}^2(0)\,p_{1/2}^1)_{1/2} + \pi(f_{7/2}^{-2}(2))_2\,\nu(p_{3/2}^2(0)\,f_{5/2}^1)_{5/2}$$

Hamanato, I., and Arimo, A. (1962). *Nucl. Phys.* **37**, 457.



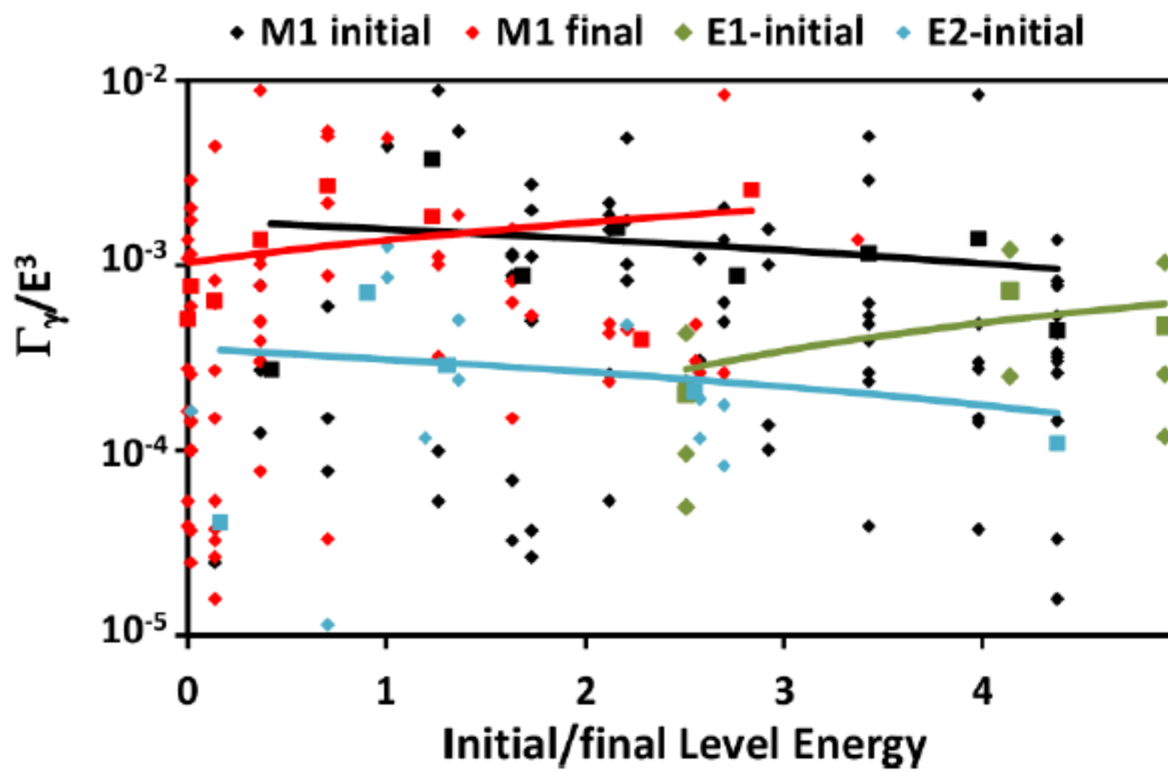
Seniority Model

Primary γ-rays

Primary M1 γ-rays will favor low energy Δν=0 transitions between levels of the same seniority differing only by residual interactions.

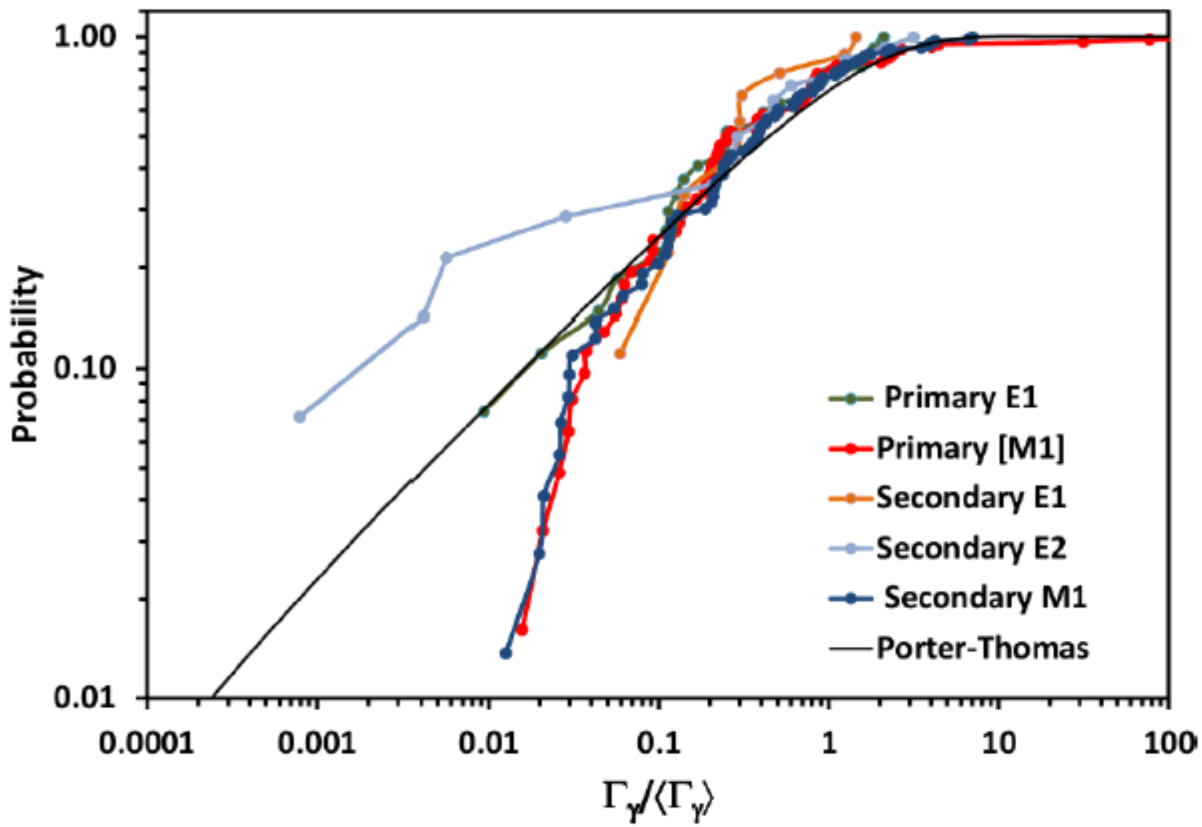
High energy primary E1 γ-rays will be dominated by the GDR.

Dependence of secondary γ-ray strength on level excitation energy



There is little dependence of the γ-ray strength on level excitation energies. A large "statistical" distribution of γ-ray strengths is associated with each initial/final level.

Statistical distribution of γ-ray strengths



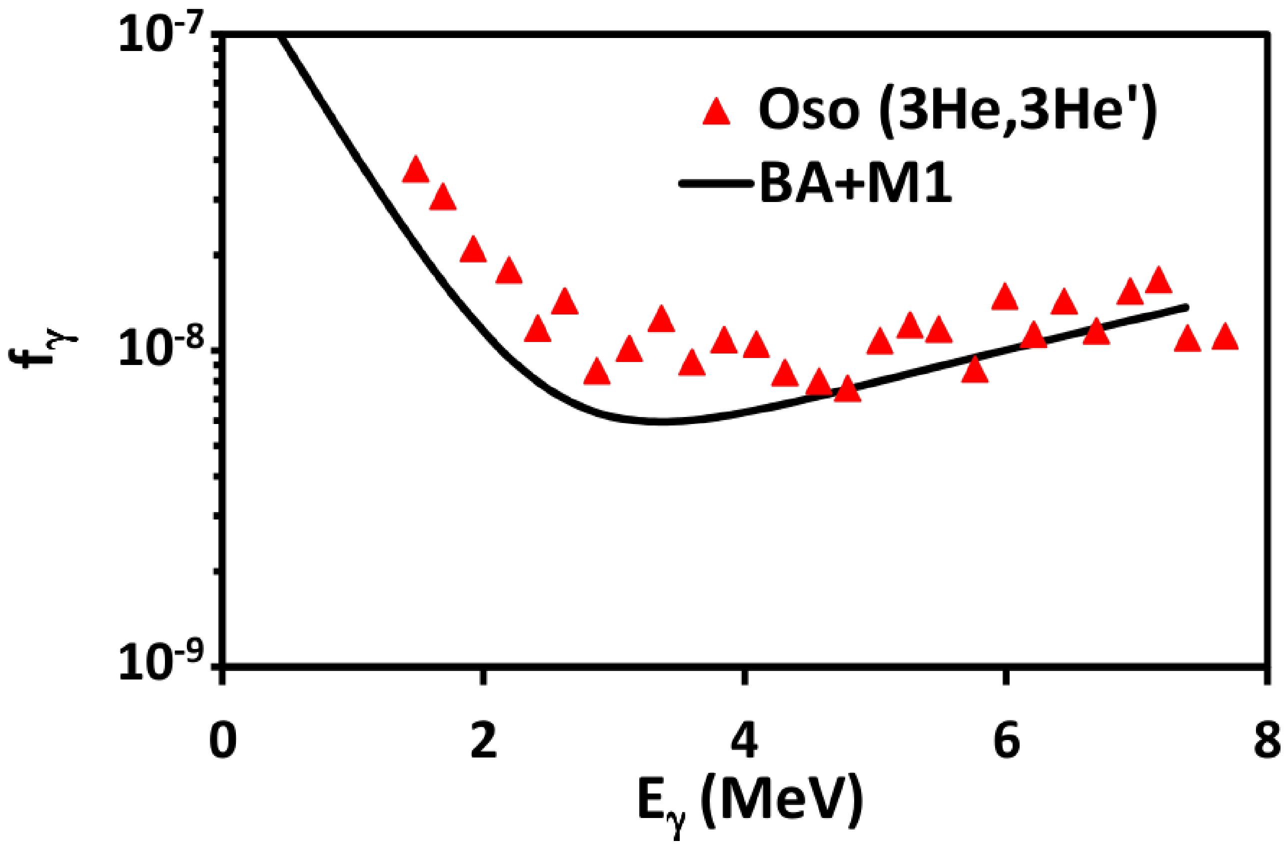
- Only E1 γ-ray strengths appear to follow a Porter-Thomas distribution.
- Weak E2 transitions exceed Porter-Thomas probability predictions.
- Both primary and secondary M1 γ-rays have fewer weak transitions than predicted by Porter-Thomas.
- Similar primary and secondary γ-ray probabilities confirm primary M1 nature

M1 strength model

The ^{57}Fe primary γ-ray M1 strength can be fit to the exponential

$$f_{\gamma}(M1)=3.93\times10^{-7}\,e^{-0.00156\cdot E_{\gamma}}$$

giving a good fit to the Oslo $^{57}Fe(^{3}He,^{3}He')$ data assuming equal M1 and E1 contributions where the E1 γ-ray strength is taken as Brink-Axel.



Conclusions

- The $^{56}Fe(n,\gamma)^{57}Fe$ level scheme is >99% complete.
- The ^{57}Fe γ-ray strengths from (n,γ) are comparable to strengths observed by reactions in Oslo.
- High-energy primary E1 γ-ray strengths are explained by Brink-Axel.
- Low-energy primary γ-ray strengths greatly exceed Brink-Axel and are consistent with M1.
- Secondary M1 γ-ray strengths also greatly exceed Brink-Axel.
- There is no evidence of any significant level energy dependence on γ-ray strength.
- E1 γ-ray strengths follow a Porter-Thomas distribution.
- E2 and M1 γ-ray strengths fail to follow a Porter-Thomas distribution.
- Similarities in the statistical distributions of M1 secondary γ-ray strengths and primary, low-energy γ-ray strengths suggests that the low-energy primary g–rays are primarily M1.
- A simple exponential M1 strength function can explain the Oslo reaction data.

Thank you for your attention