Experimental Determination of Photon Strengths for 0-10 MeV Gamma Rays

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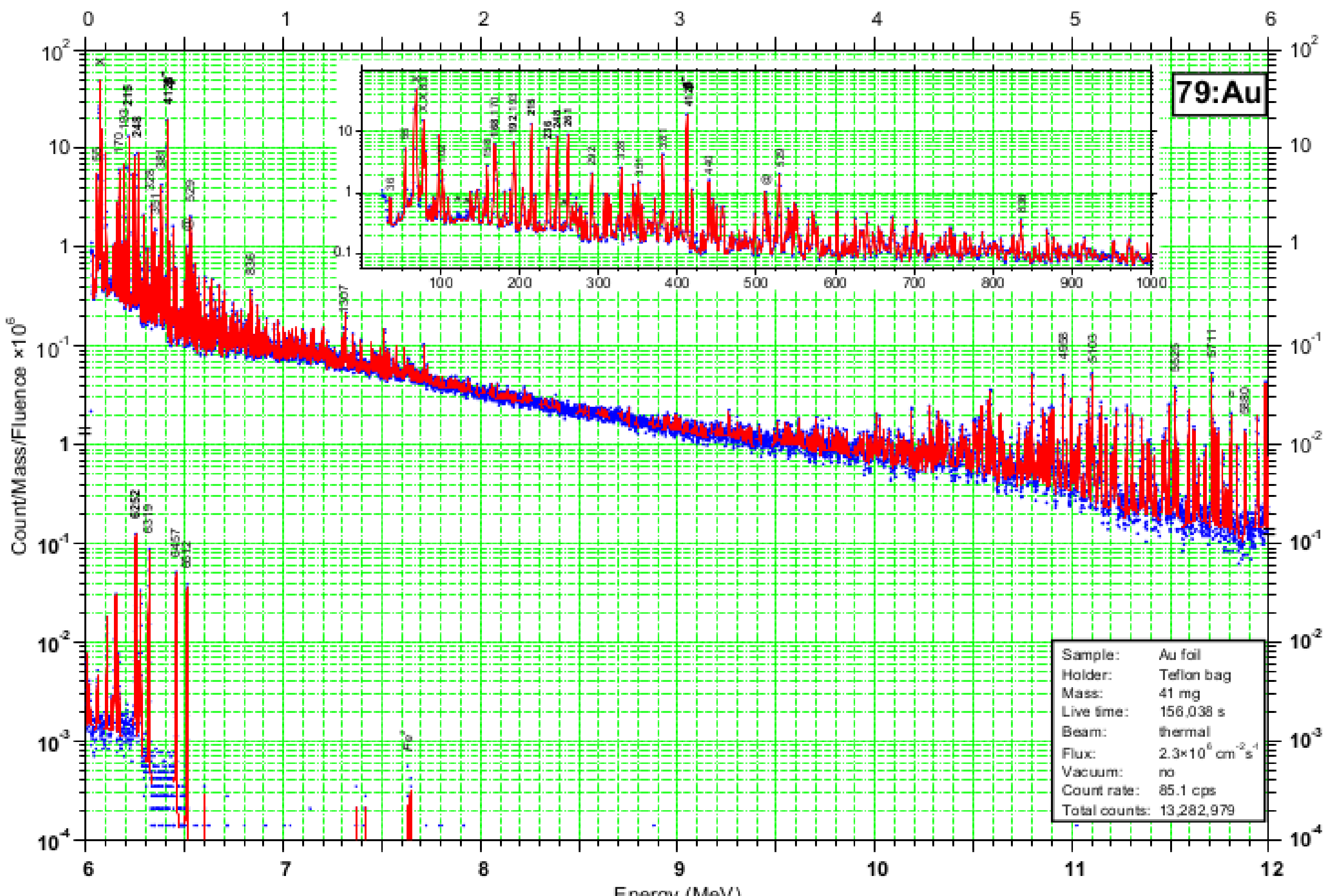


Photon Strength

Definition: $f(E_\gamma) = {}^{\sigma_{abs}}\!/_{3(\pi\hbar c)^2 E_\gamma} = {}^{P_\gamma \Gamma_\gamma}\!/_{d_0 E_\gamma^3}$

σ_{abs}=photonuclear cross section (γ,n)
P_γ=primary γ-ray transition probability (n,γ)
E_γ= primary γ-ray energy (MeV)
Γ_γ = capture state width (eV)
d_0 = average level spacing at E_{excit}

For EGAF thermal capture data: $P_\gamma = \sigma_\gamma / \sigma_0$

σ_γ = primary γ-ray cross section (b)
σ_0 = total radiative neutron cross section (b) – Atlas*
Γ_γ, d_0 - Atlas*

For ENSDF level data (new): $P_\gamma = I_\gamma / \Sigma I_\gamma (1+\alpha)$ (level)

$\Gamma_\gamma = \ln(2) * \hbar / t_{1/2}$
d_0 from level density models

*Atlas of Neutron Resonances, S.F. Mughabghab, Elsevier (2006)

E1 Photon Strength Models

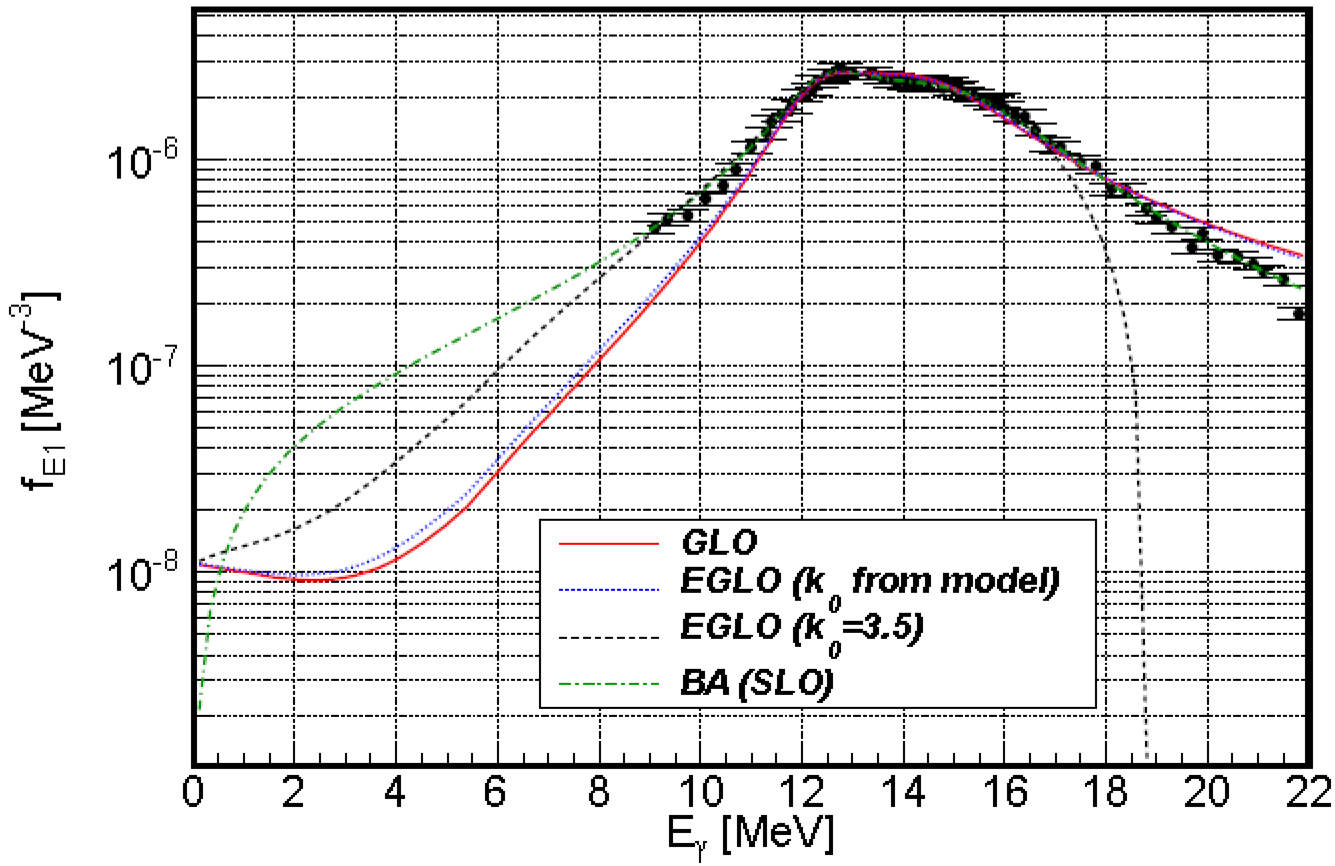
Brink-Axel: $f_{BA}^{E1}(E_\gamma) = \frac{1}{3(\pi\hbar c)^3} \sum_{i=1}^{i=2} \frac{\sigma_{G_i} E_\gamma \Gamma_{G_i}^2}{(E_\gamma^2 - E_{G_i}^2)^2 + E_\gamma^2 \Gamma_{G_i}^2}$, where $E_{G_i}^2$, $\Gamma_{G_i}^2$, σ_{G_i} are the energy, width, and cross section for the GDR. In deformed nuclei there are two (i=1,2) sets of GDR parameters.

KMF: $f_{GLO}^{E1}(E_\gamma, \theta) = \sum_{i=1}^{i=2} \frac{\sigma_{G_i} \Gamma_{G_i}}{3(\pi\hbar c)^3} \left[F_k \frac{4\pi^2\theta^2\Gamma_{G_i}}{E_{G_i}^5} + \frac{E_\gamma \Gamma_{G_i}(E_\gamma,\theta)}{(E_\gamma^2 - E_{G_i}^2)^2 + E_\gamma^2 \Gamma_{G_i}^2(E_\gamma,\theta)} \right]$

where $F_k = 0.7$ (Fermi liquid parameter); $\theta = \sqrt{(E_{ex} - \Delta)/a}$ is the nuclear temperature, a function of final level excitation energy, and pairing energy $\Delta = +0.5|P_d|$(even-even A), 0 (odd A), or $-0.5|P_d|$(odd-odd A), P_d is the deuteron pairing energy; and $a \sim 0.21 A^{0.87} MeV^{-1}$ is the shell model level density parameter. $\Gamma_{G_i}(E_\gamma, \theta) = \frac{\Gamma_{G_i}}{E_{G_i}^2}(E_\gamma^2 + 4\pi^2\theta^2)$

EGLO: $\Gamma'_{G_i}(E_\gamma, \theta) = \left[k_0 + (1 - k_0) \frac{(E_\gamma - E_0)}{(E_{G_i} - E_0)} \right] \Gamma_{G_i}(E_\gamma, \theta)$, $E_0 = 4.5\ MeV$. The constant k_0 is an empirical enhancement factor for the width suggested by Kopecky.

Comparison of ^{186}W photonuclear data with E1 Strength Models



^{186}W(γ,abs) photonuclear data from Berman et al, Phys. Rev. 185, 1576 (1969).

$$f(E_\gamma) = {}^{\sigma_{abs}}\!/_{3(\pi\hbar c)^2 E_\gamma}$$

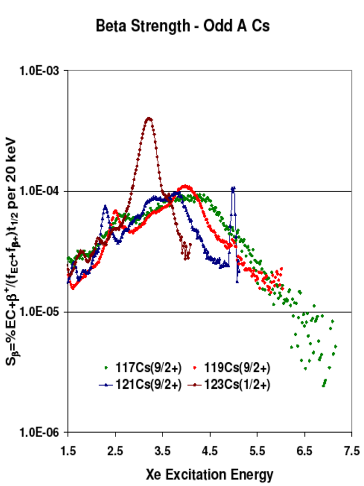
M1 Photon Strength Functions

Single particle model: $f_{SP}^{(M1)} = constant$

GDMR Model: $f_{GDMR}^{(M1)} \propto f_{BA}^{(E1)}$

Both models are insufficient.

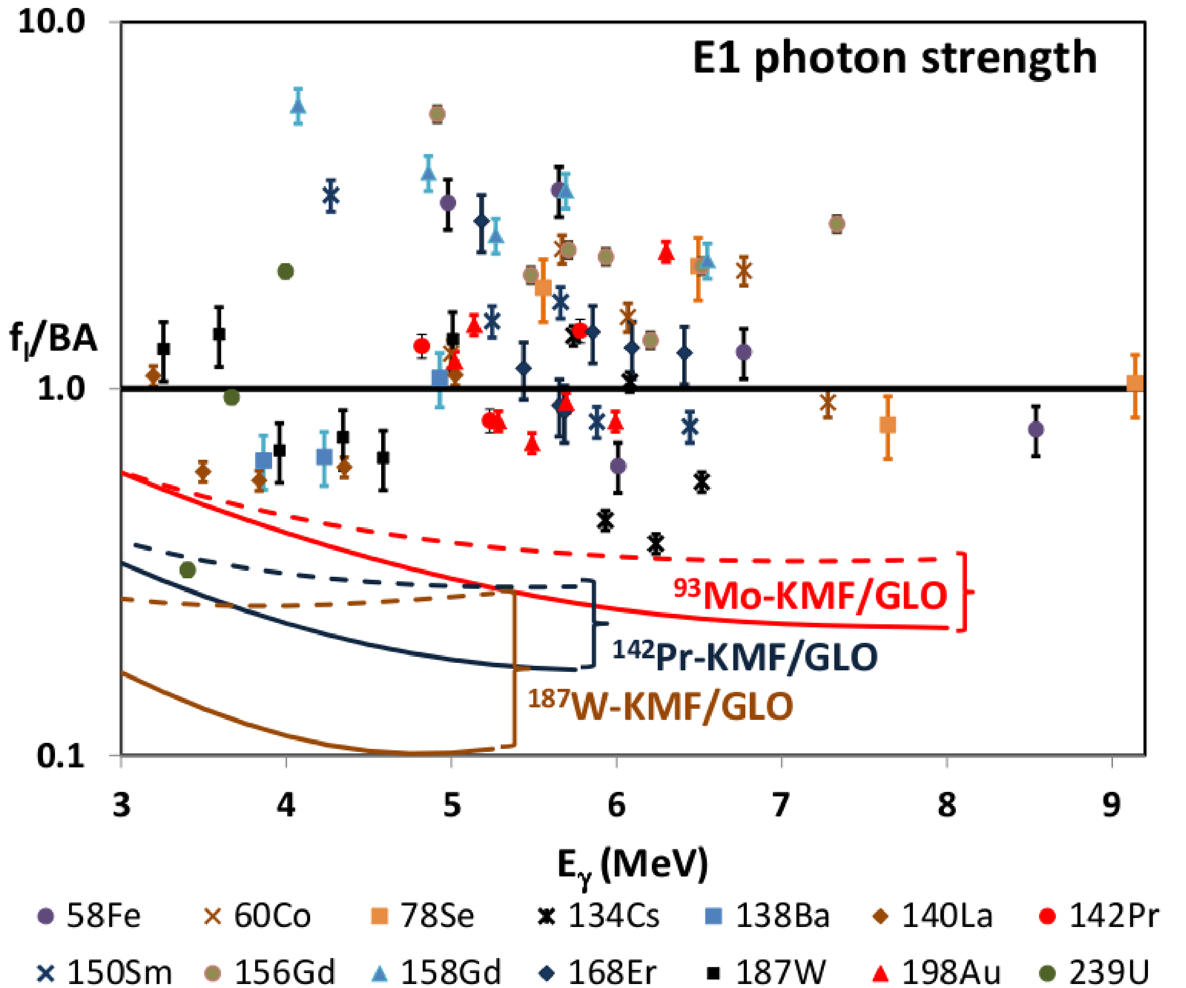
Beta-decay strength functions – analogous to M1 γ-ray transitions.



Gross theory of beta decay – basically equivalent to GDMR model.

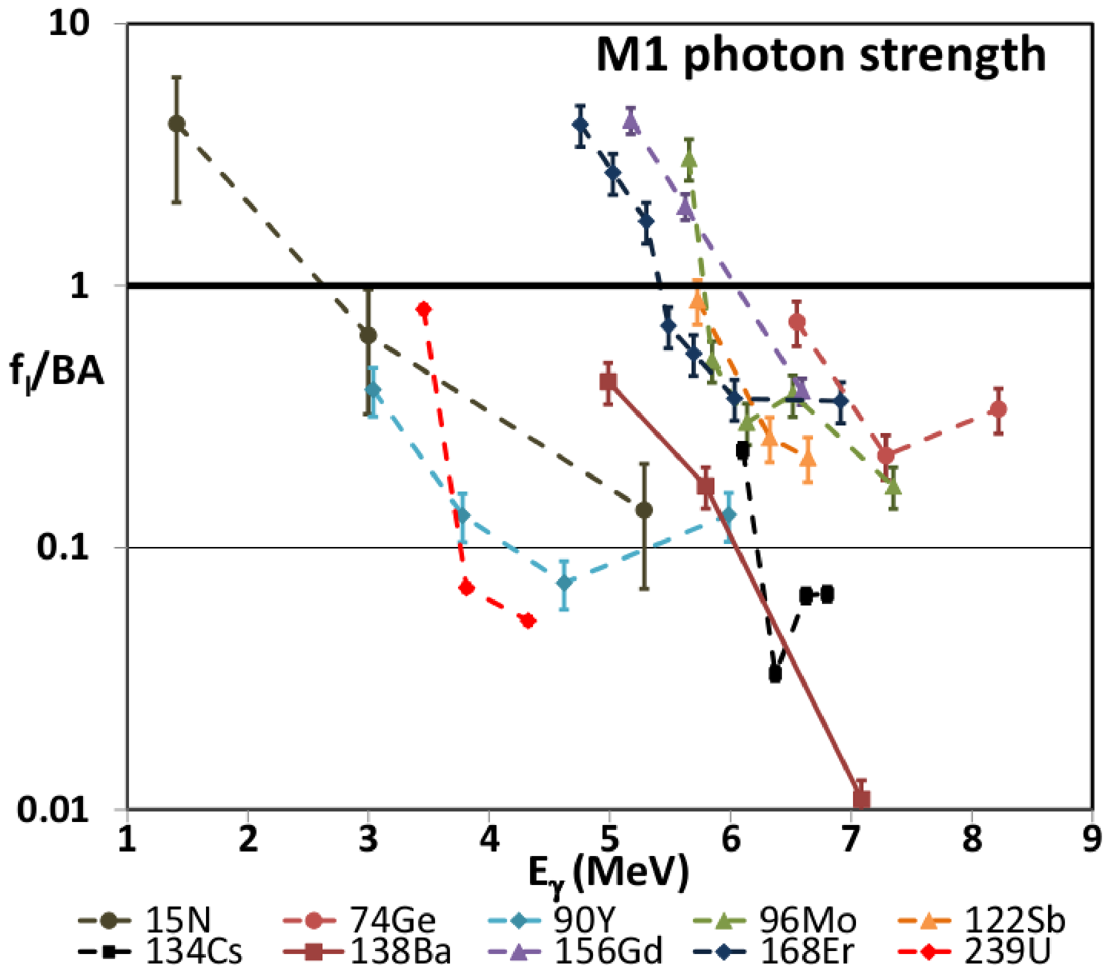
- Predicts substantial decay to level excitations with high level density
- Experimentally little beta strength is observed to high lying levels
- Conclusion: There is no significant GDMR

Primary γ-ray E1 Strength Systematics



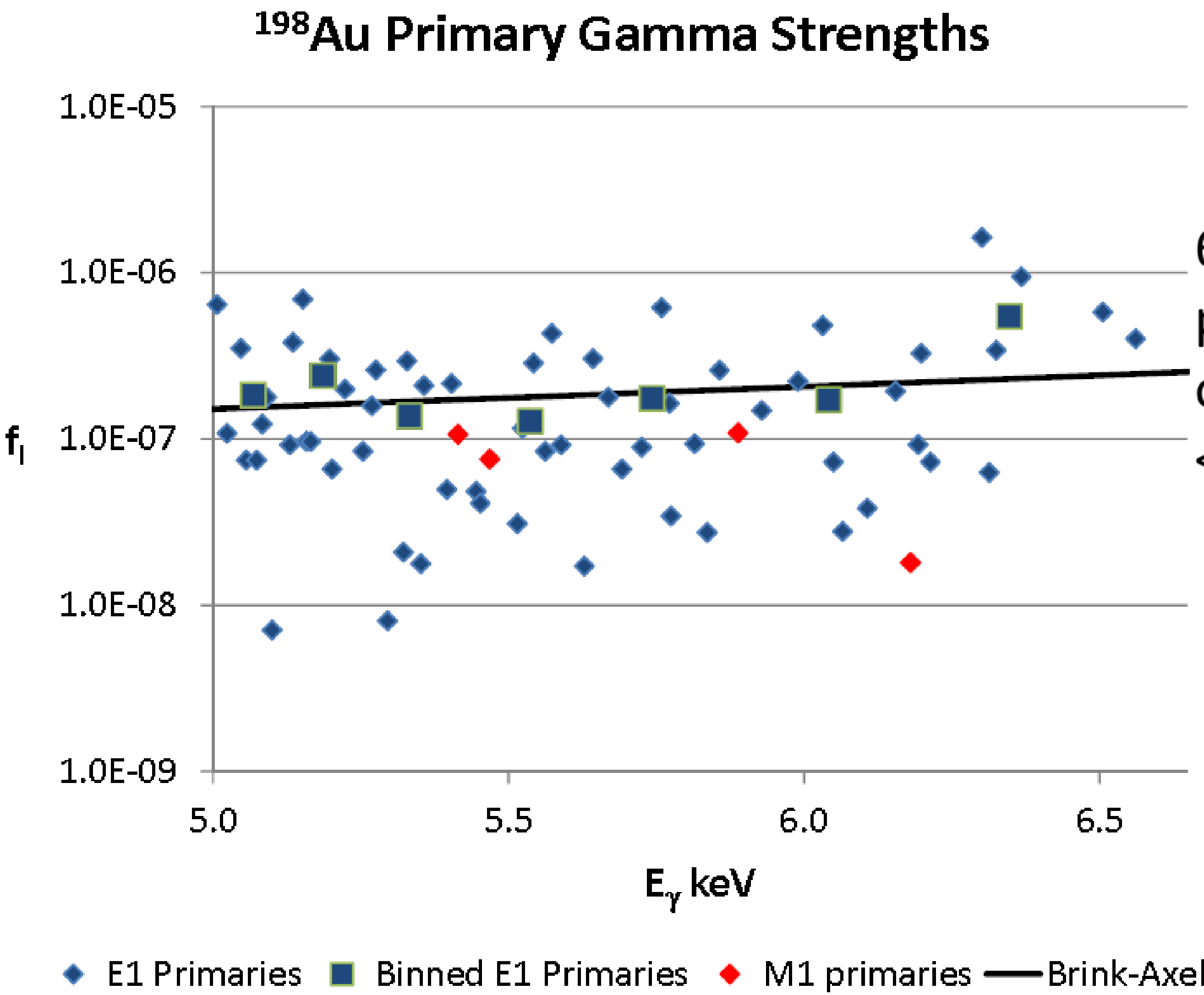
Comparison of **observed** binned average photon strengths.

Primary γ-ray M1 Strength



M1 photon strengths comparable or stronger than E1 at low energies.

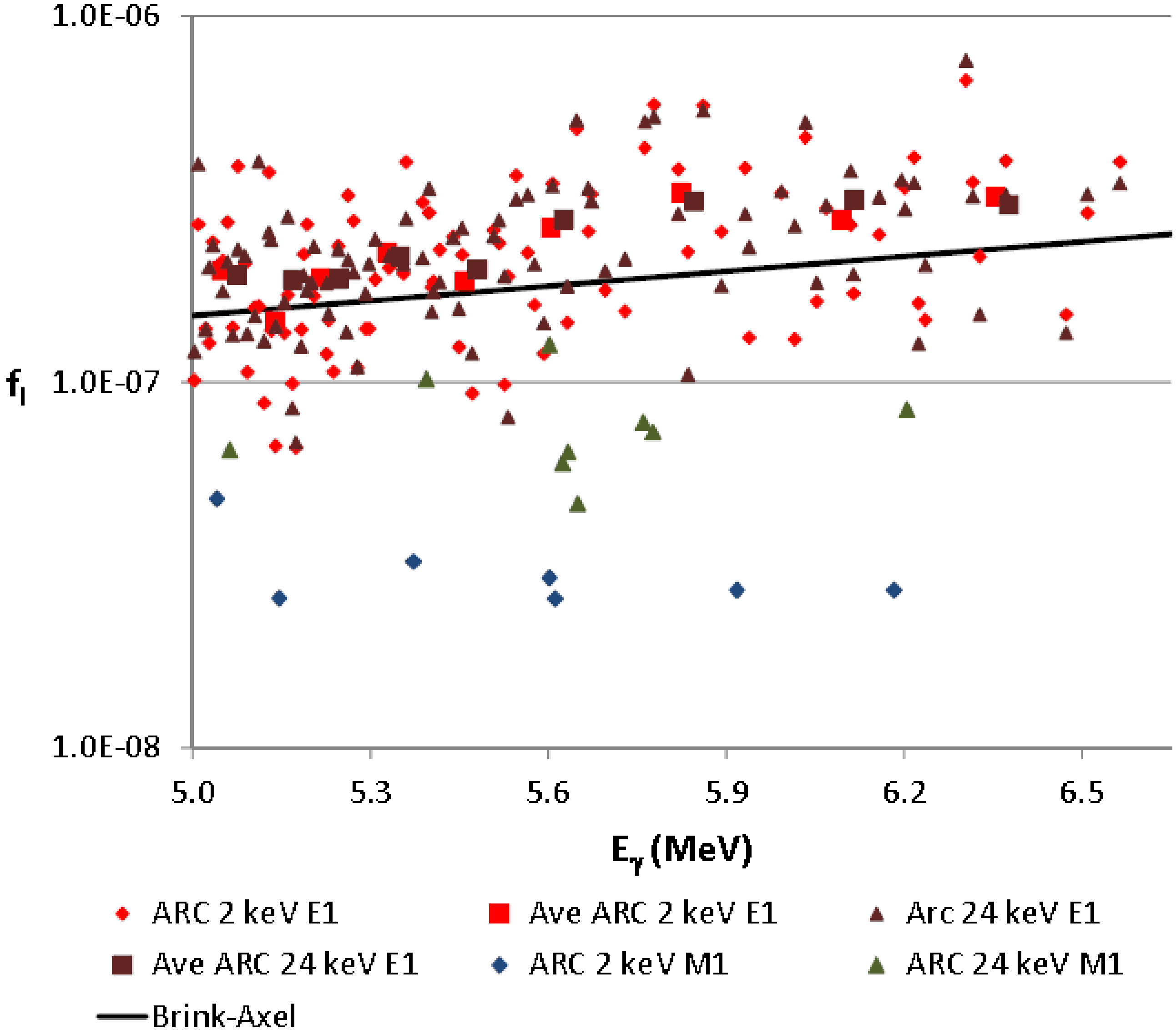
Thermal Primary Photon Strength



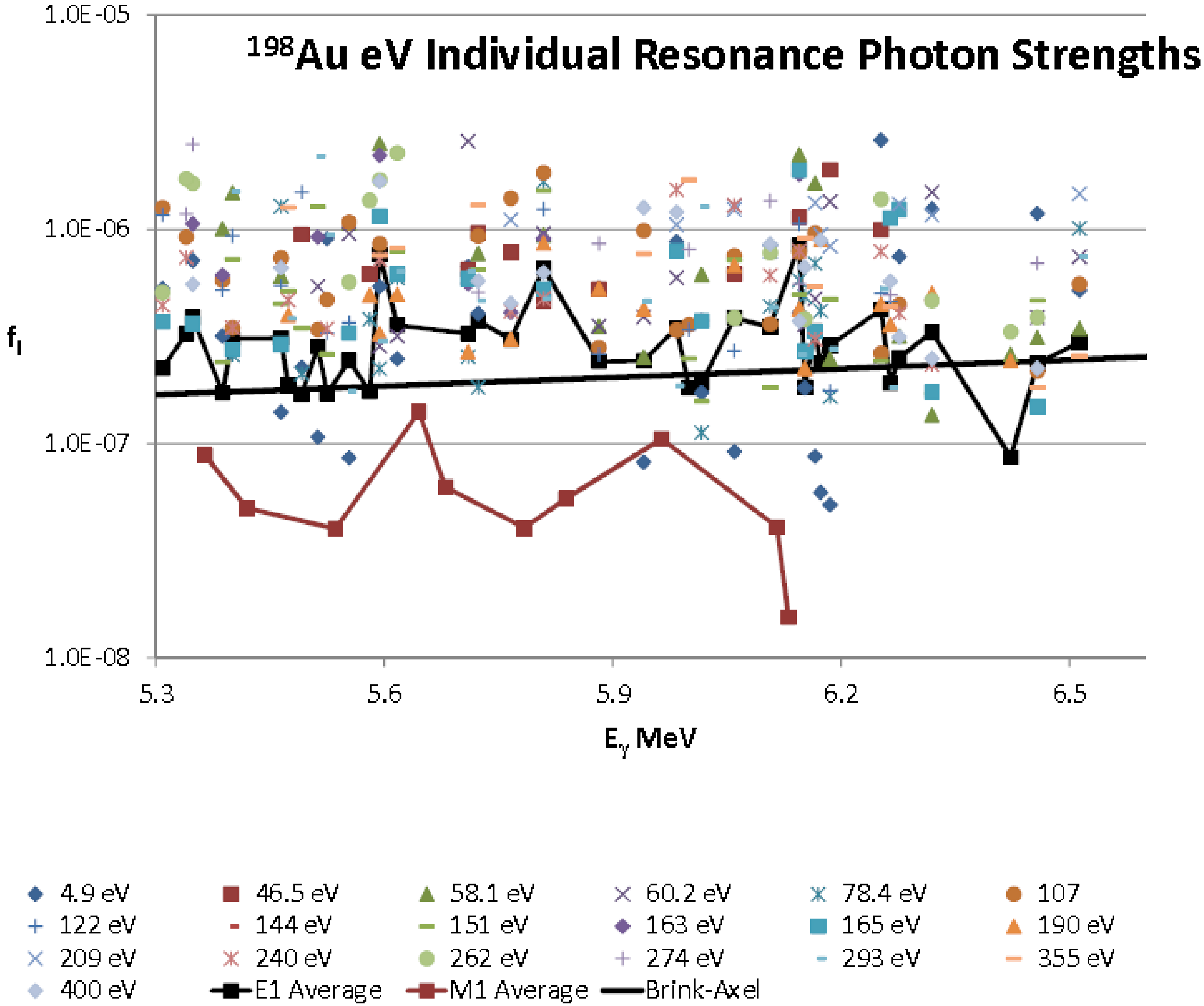
62 E1 and 4 M1 primary γ-rays observed to levels <1555 keV.

$$f(E_\gamma) = {P_\gamma \Gamma_\gamma}\big/{d_0 E_\gamma^3}$$

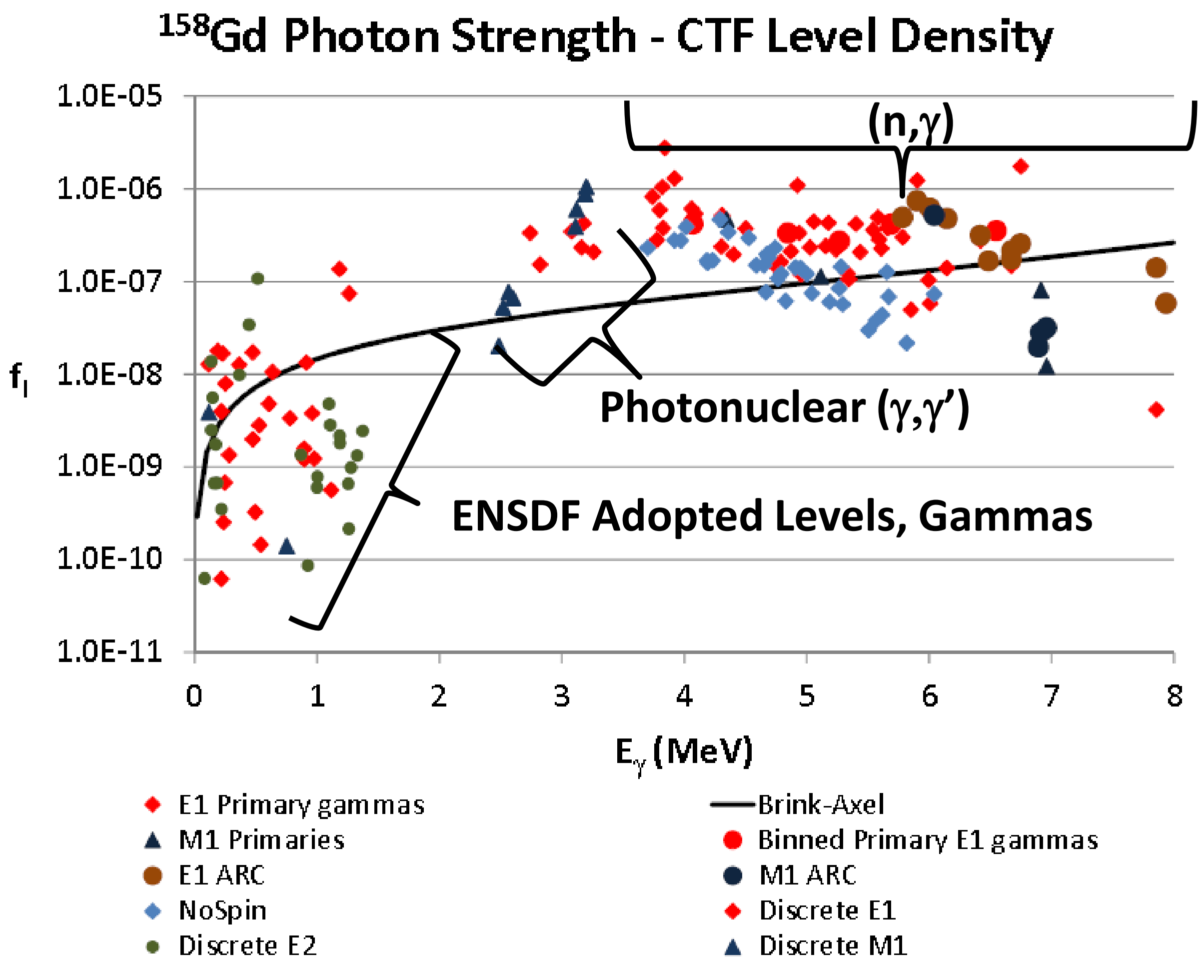
^{198}Au 2, 24 keV ARC Primary Photon Strengths



NTOF Photon Strengths

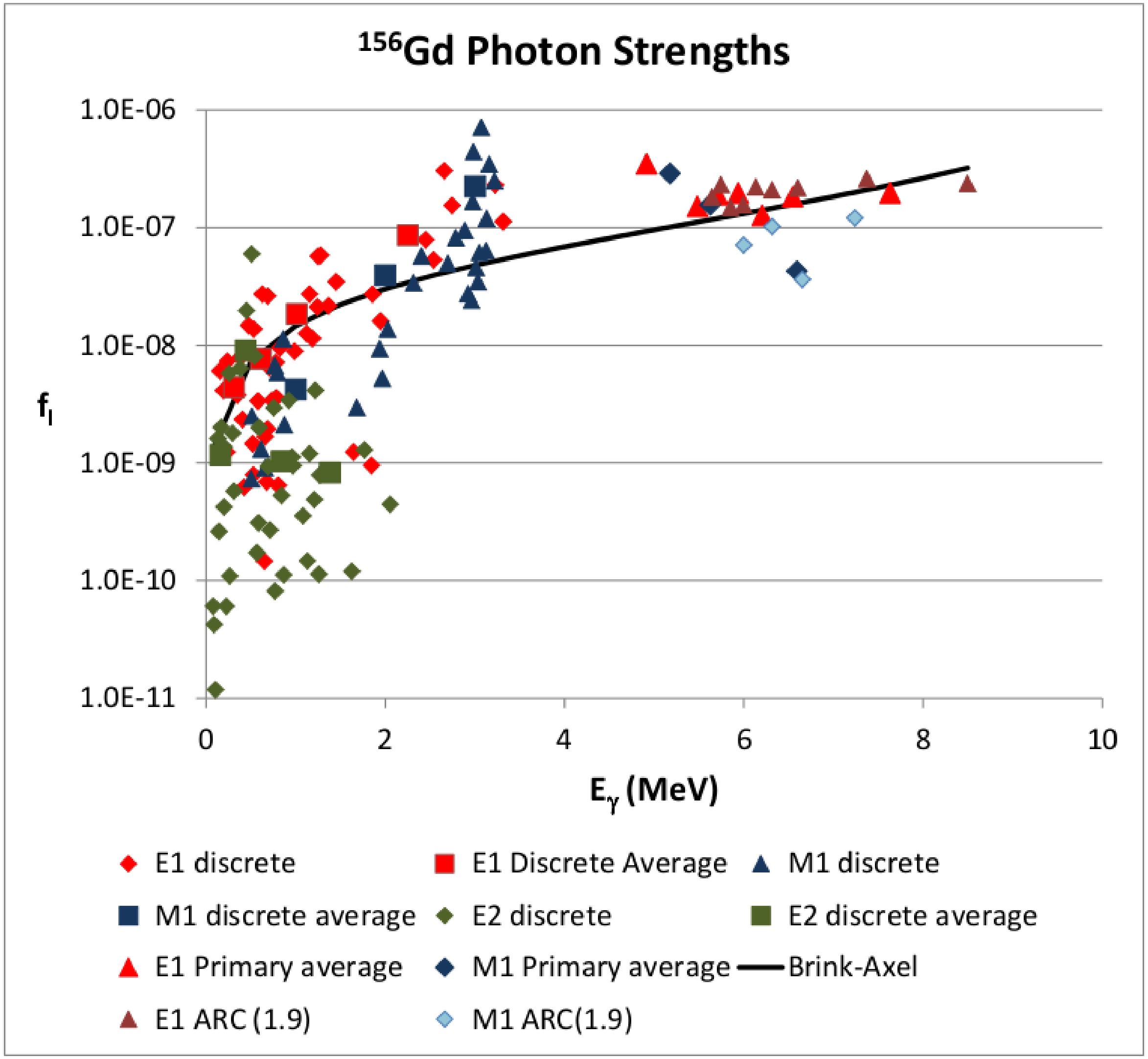


^{158}Gd Photon Strengths



Data from ENSDF Adopted Levels with measured lifetimes and theoretical level densities can be used to calculate low-energy γ-ray strengths.

^{156}Gd Photon Strengths



IAEA Consultants Meeting on a Database of Photon Strength Data

Compilation and Evaluation of Gamma-Ray Data

4-6 November, 2013

Participants:

F. Becvar – Charles University in Prague

P. Dimitriou - IAEA

R.B. Firestone – LBNL

M. Krticka – Charles University in Prague

S. Siem – University of Oslo

V. Varmalov – Moscow State University

M. Wiedeking – iThema Laboratories, S. Africa

Motivation

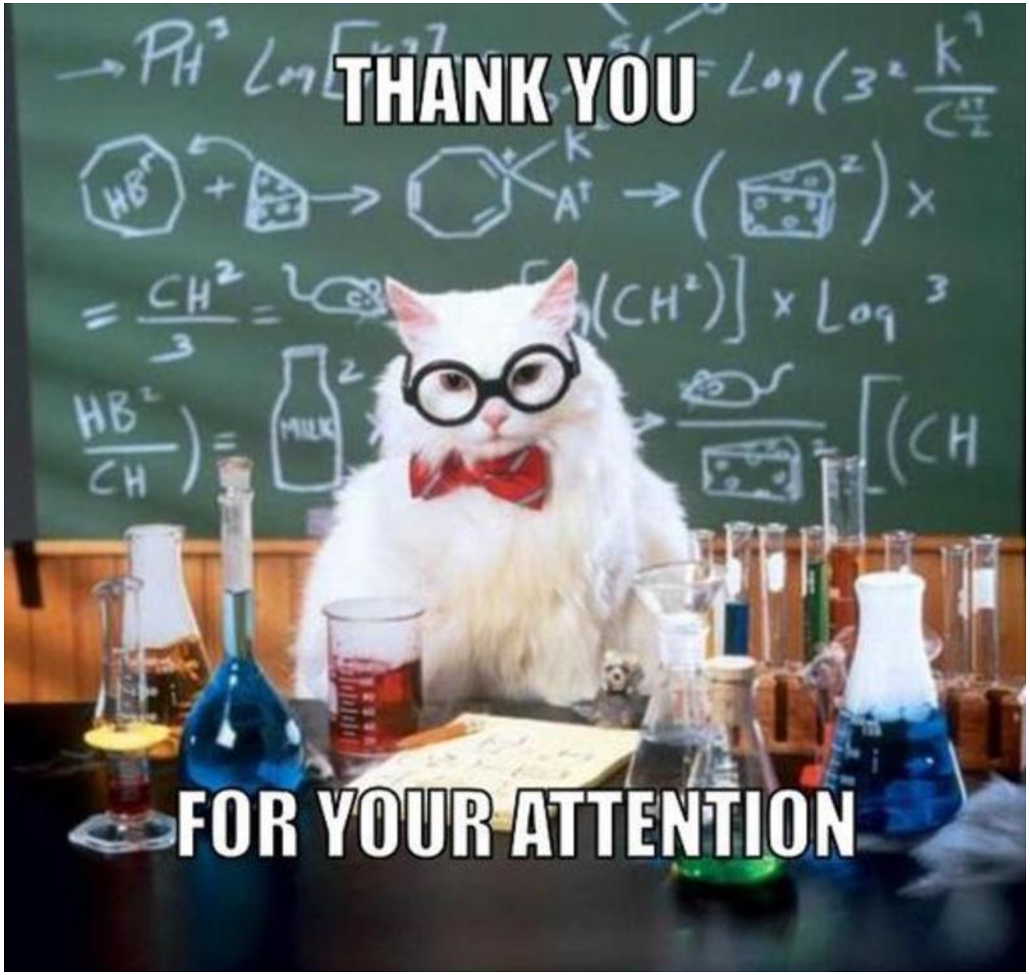
Gamma-ray data from nuclear reactions are important for a large range of applications, as well as for basic sciences. In particular, gamma-ray data to extract photon strength functions and photonuclear cross sections are necessary for energy, safety and medical applications as well as for nuclear physics and astrophysics.

There is an explosion of gamma-ray data related to photonuclear reactions and photon strength functions in recent years that needs to be compiled and evaluated, and made available to researchers worldwide. These data are important sources of information for other evaluated data files supported by the IAEA such as RIPL, ENDF, EGAF, ENSDF etc, however there is no comprehensive database that includes all these data. They are also of use for the development and improvement of theoretical models describing the electromagnetic response of the nucleus.

The reaction gamma-ray community, in the 4th Level Density and Gamma Strength Workshop in Oslo, May 2013, expressed a strong interest to have a reaction gamma-ray database under the auspices of the IAEA.

Recommendations

- There is an urgent need for the compilation and evaluation of all relevant data in a dedicated database.
- The IAEA should initiate a CRP with the primary task of compiling the relevant data, defining the database structure and formats, outlining the evaluation methodology, assessing experimental methods and understanding the source of discrepancies.
- The CRP should also propose a priority list for new measurements and perform benchmark comparisons of data from multiple experiments using different techniques on a given isotope.
- The project should include participants who have expertise in crucial aspects of photonuclear and gamma-ray reaction measurements and analysis.
- The consultants also recommend that the IAEA disseminate the DICEBOX code for analysis of γ-ray data in coordination with the group from Charles University in Prague.


THANK YOU
FOR YOUR ATTENTION