LA-UR-22-21626

Available Photonuclear Reaction Data and Libraries, and Evaluation Method

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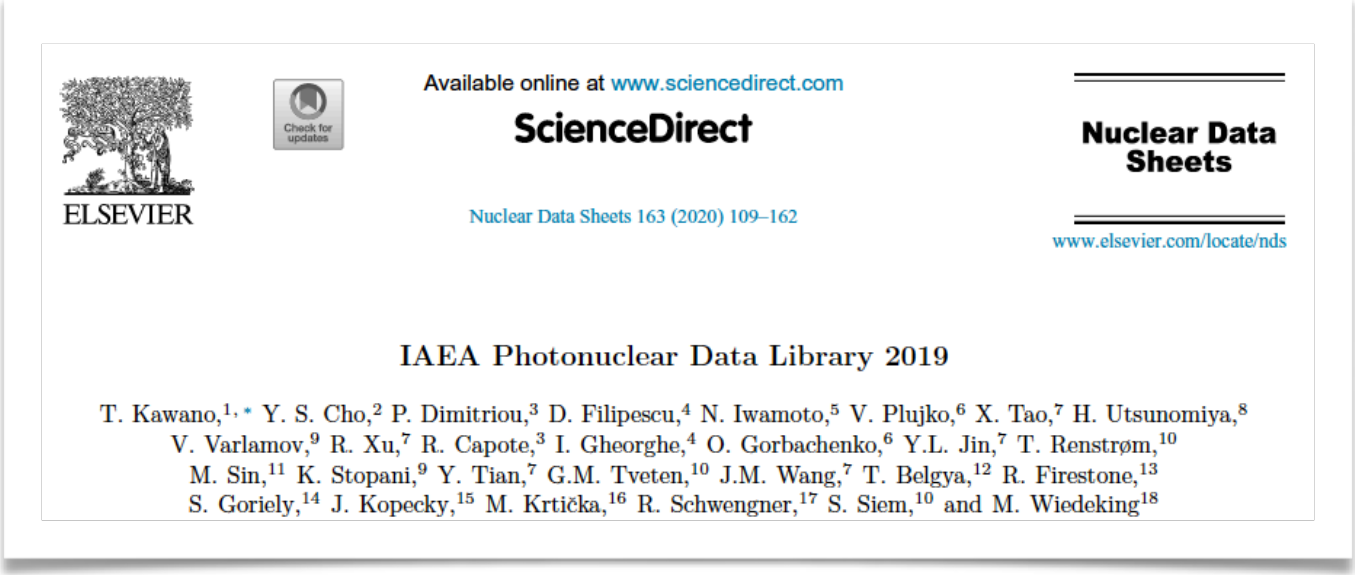
Major Photonuclear Data Libraries

- IAEA photonuclear data library released in 1999
  - IAEA Coordinated Research Project, chaired by M.B. Chadwick
  - 164 isotopes evaluated based largely on model calculations (GNASH and others)
- ENDF photonuclear data library adopted IAEA1999 with some upgrades
- JENDL photonuclear data libraries
  - JENDL/PD-2004, JENDL/PD-2016, and JENDL/PD-2016.1 (181 in standard version, 2681 in extended)
  - older evaluations by ALICE-F, and upgraded by CCONE

- IAEA 2019
  - New IAEA CRP, including both the photon strength function and photonuclear data library
  - 219 isotopes, extended photon energy of 200 MeV
  - Nuclear Data Sheets **163**, 109 (2020)



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Nuclear Data Sheets

Nuclear Data Sheets 163 (2020) 109–162

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IAEA Photonuclear Data Library 2019

T. Kawano,[1,*] Y. S. Cho,[2] P. Dimitriou,[3] D. Filipescu,[4] N. Iwamoto,[5] V. Plujko,[6] X. Tao,[7] H. Utsunomiya,[8] V. Varlamov,[9] R. Xu,[7] R. Capote,[3] I. Gheorghe,[4] O. Gorbachenko,[6] Y.L. Jin,[7] T. Renstrøm,[10] M. Sin,[11] K. Stopani,[9] Y. Tian,[7] G.M. Tveten,[10] J.M. Wang,[7] T. Belgya,[12] R. Firestone,[13] S. Goriely,[14] J. Kopecky,[15] M. Krtička,[16] R. Schwengner,[17] S. Siem,[10] and M. Wiedeking[18]

IAEA Photonuclear Data Library 2019

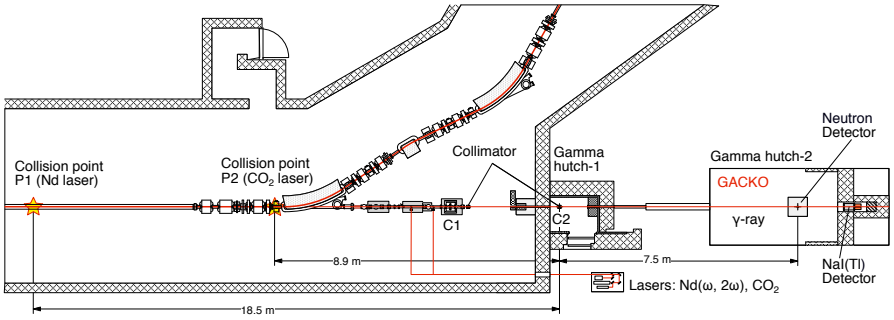
- New experimental data provided by NewSUBARU, Laser Compton Scattering Facility by Utsunomiya
- Evaluation of existing experimental data by Varlamov
  - Neutron-counting experiments, (g,1n), (g,2n) etc, sometimes show cross-talk between different reaction channels
  - They were “corrected” by CPNRM, and data in EXFOR marked as “evaluated”
- Evaluated data produced by several institutes with different HF codes
  - Cho (KAERI) uses TALYS
  - Filipescu et al. (IFIN-HH), EMPIRE
  - Iwamoto (JAEA), CCONE
  - Xu et al. (CIAE), GLUNF for light elements, MEND-G for medium to heavy
  - Kawano (LANL) didn’t produce actual files but performed calculations with CoH_3

Available Experimental Data

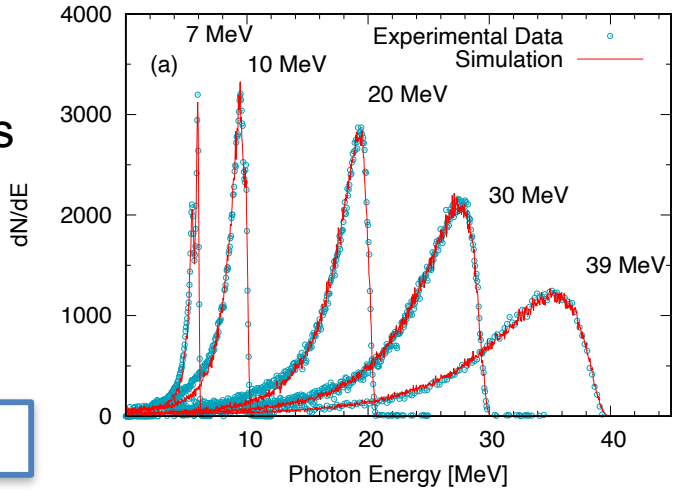
- Bremsstrahlung
  - continuous energy spectrum requires unfolding
  - quasi mono-energetic photons by tagging - U. Illinois
- Positron annihilation produces quasi mono-energetic photons
  - Saclay and LLNL

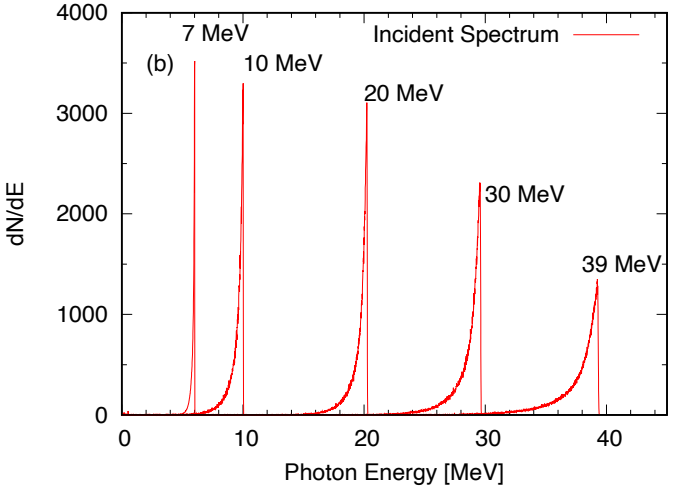
Data are available in EXPOR, but need some interpretation

- Laser Compton scattering - NewSUBARU



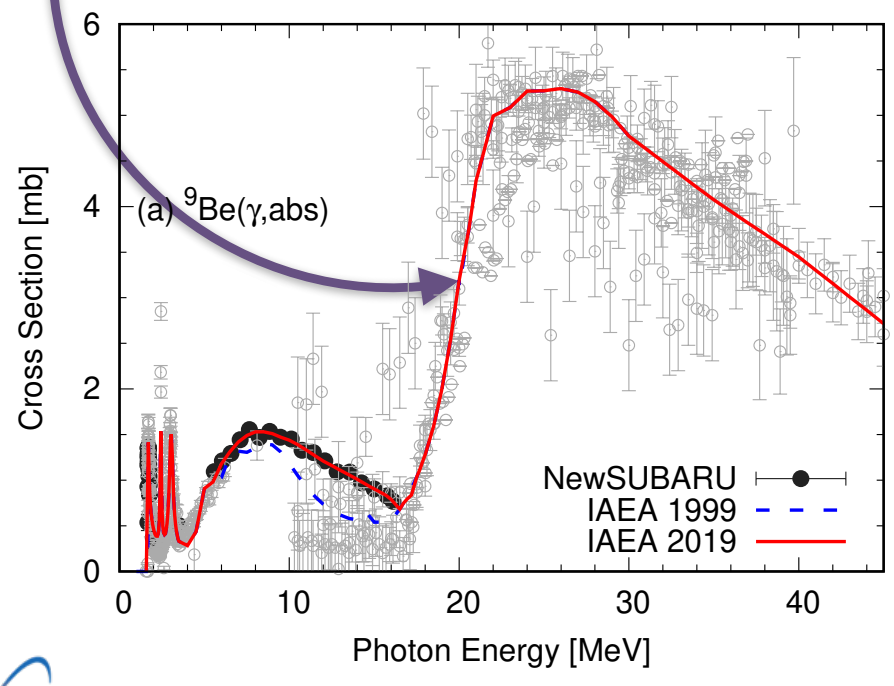
- HIgS (TUNL), ELI (EU)

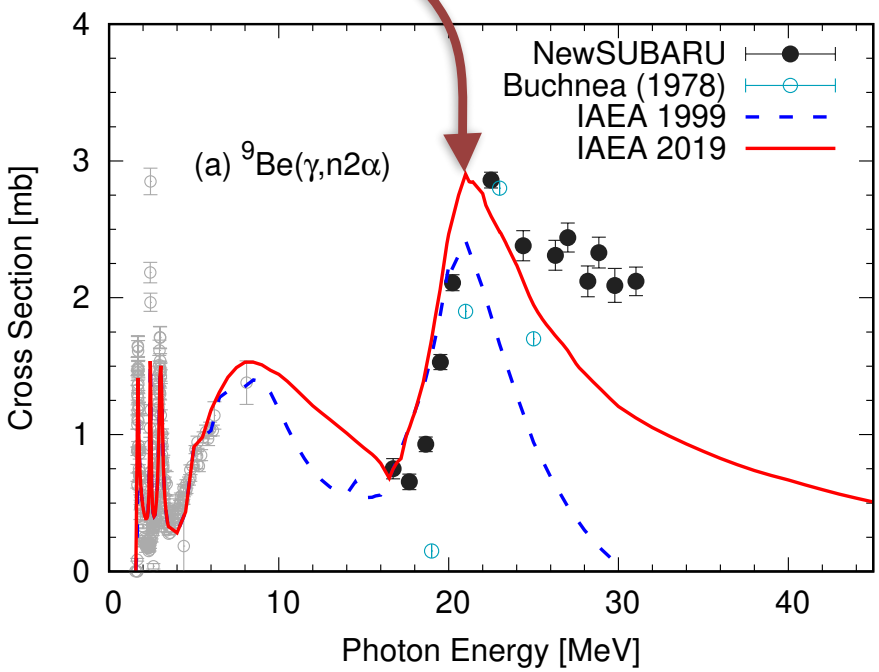




Typical Evaluation Method, Light Element

- R-matrix analysis very limited (no evaluation in IAEA2019)
- Hybrid method
  - Photo-absorption cross section taken from experimental data
  - Hauser-Feshbach statistical decay calculation





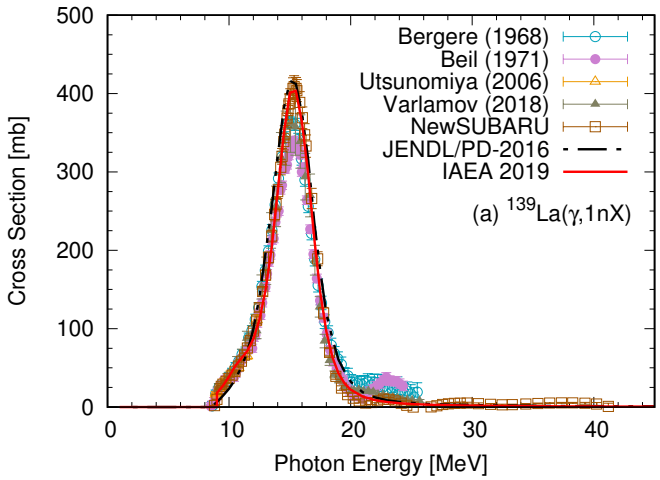
Evaluation Method, Medium to Heavy Nuclei

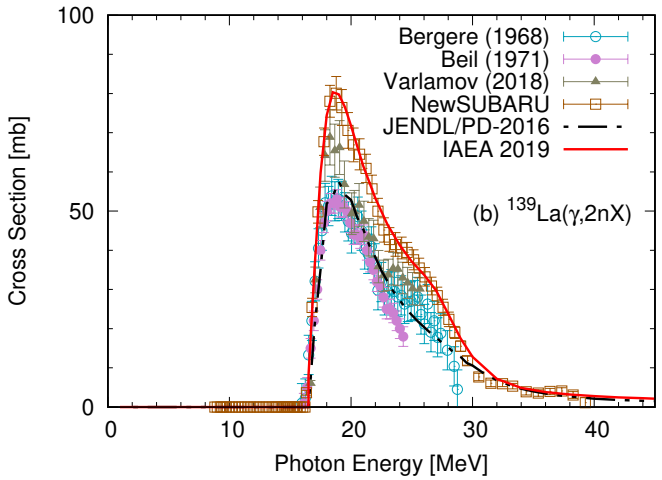
- Full Hauser-Feshbach model calculation
  - Photo-absorption = Giant Dipole Resonance + Quasi-Deuteron model
    - GDR parameterized by Lorentzian

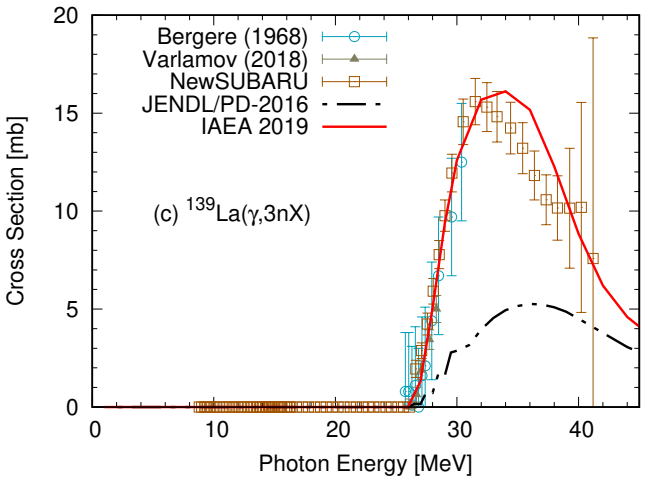
$$\sigma_{\mathrm{GDR}} = \sigma_R \frac{E_\gamma^2 \Gamma_R^2}{(E_R^2 - E_\gamma^2)^2 + E_\gamma^2 \Gamma_R^2}$$

    - QD photo-absorption by Levinger, Chadwick, at higher energies

$$\sigma_{\mathrm{QD}} = L \frac{NZ}{A} \sigma_d P_b$$

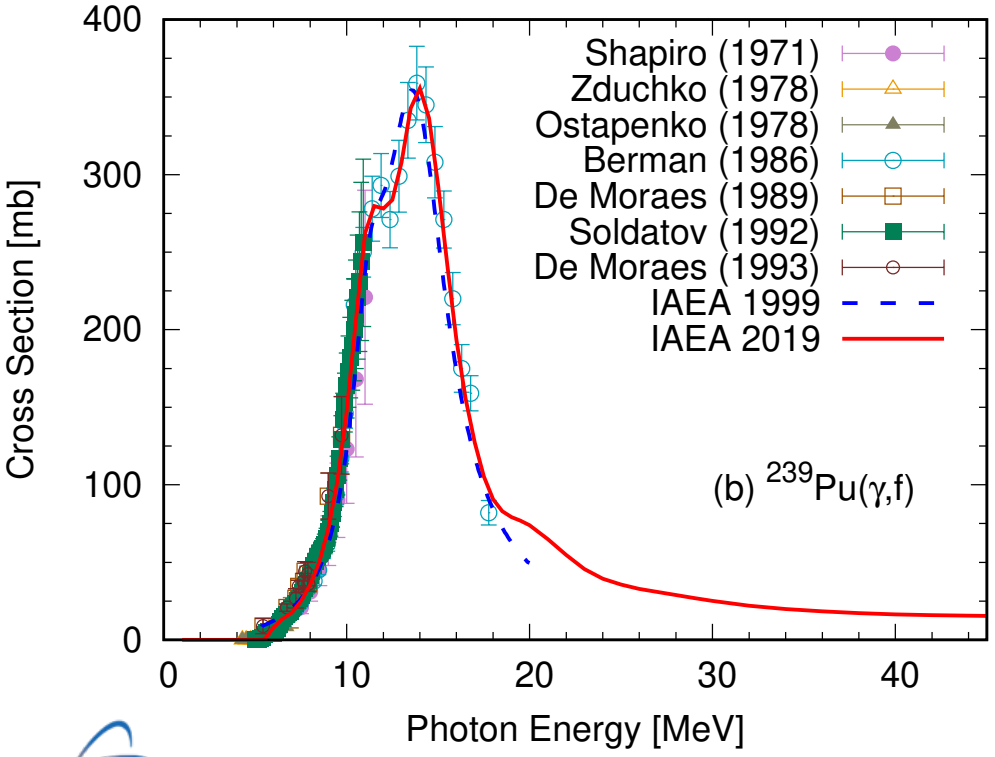


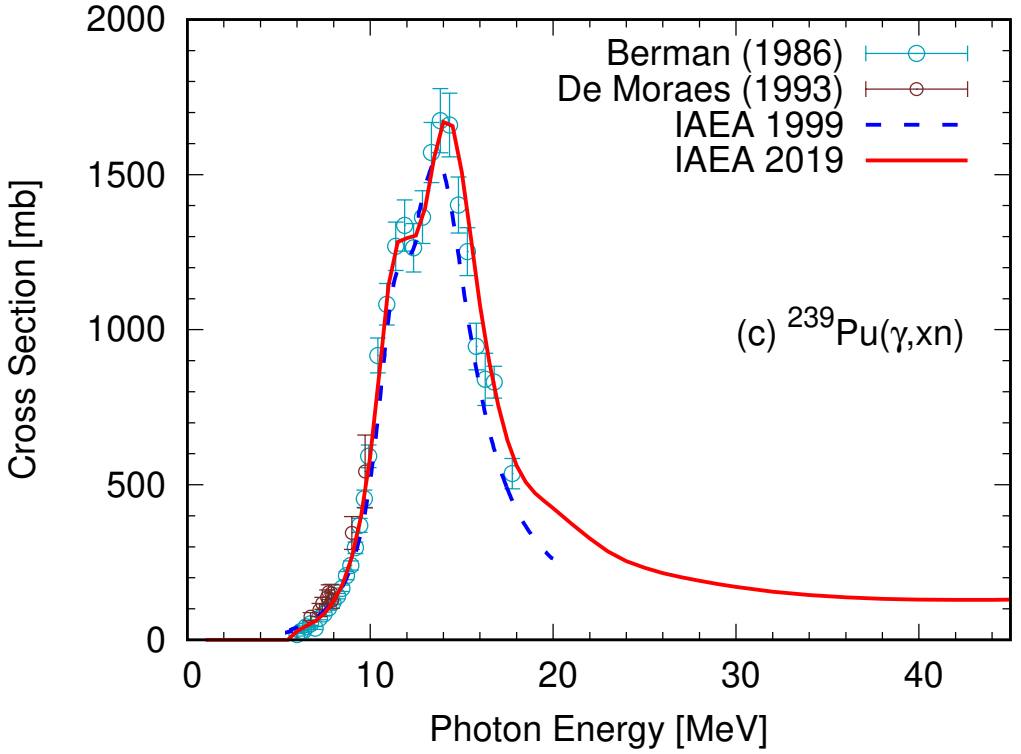




Evaluation Method, Actinide

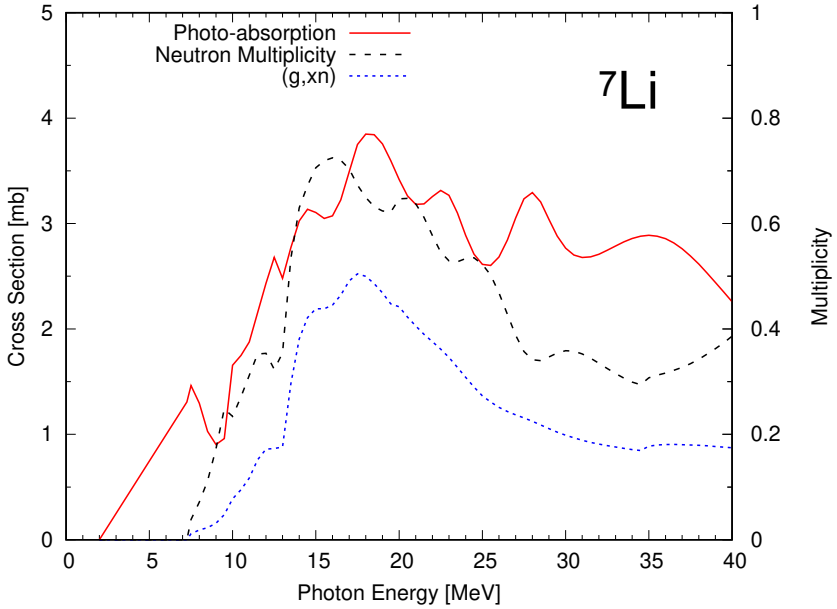
- All actinide evaluations in IAEA2019 evaluated by Iwamoto with CCONE
  - Photo-fission calculated with Hauser-Feshbach
  - or taken from neutron-induced library

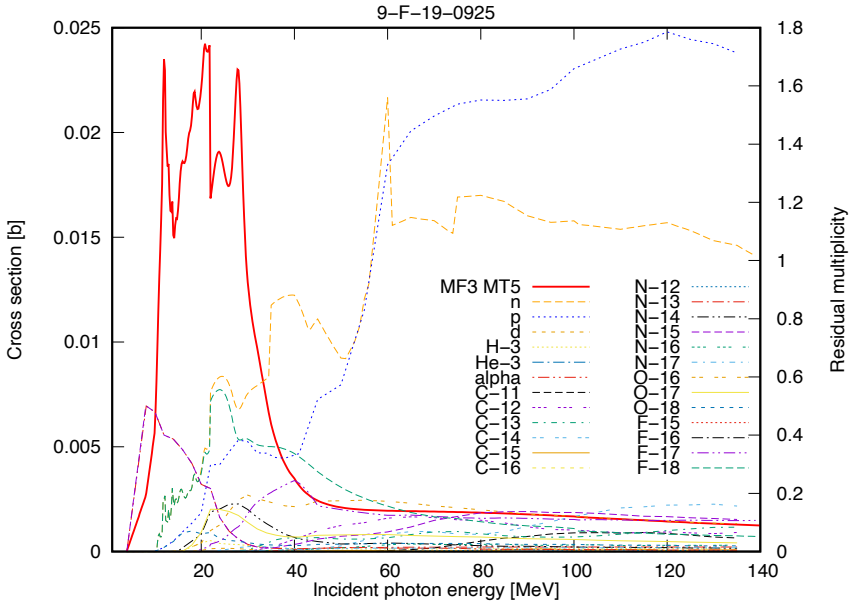




Data Compilation and Representation

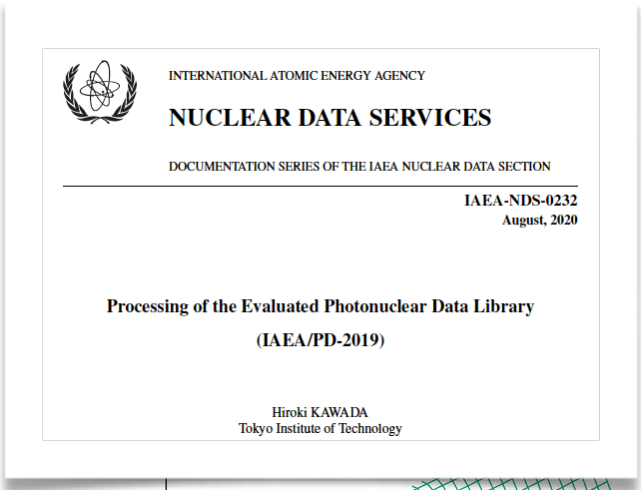
- Two approaches to store all the calculated results in an evaluated file
  - Inclusive: Total absorption cross section given in MF3 MT5 (3), then production of residual nuclei and/or emitted particles given in MF6
  - Exclusive: Cross sections for each channels given in MF3
  - There are 6 different data representation given in IAEA2019 (IAEA-NDS-0232)





This is not the issue, but often causes problems when compared with experimental data

Data Processing Issue


INTERNATIONAL ATOMIC ENERGY AGENCY

NUCLEAR DATA SERVICES

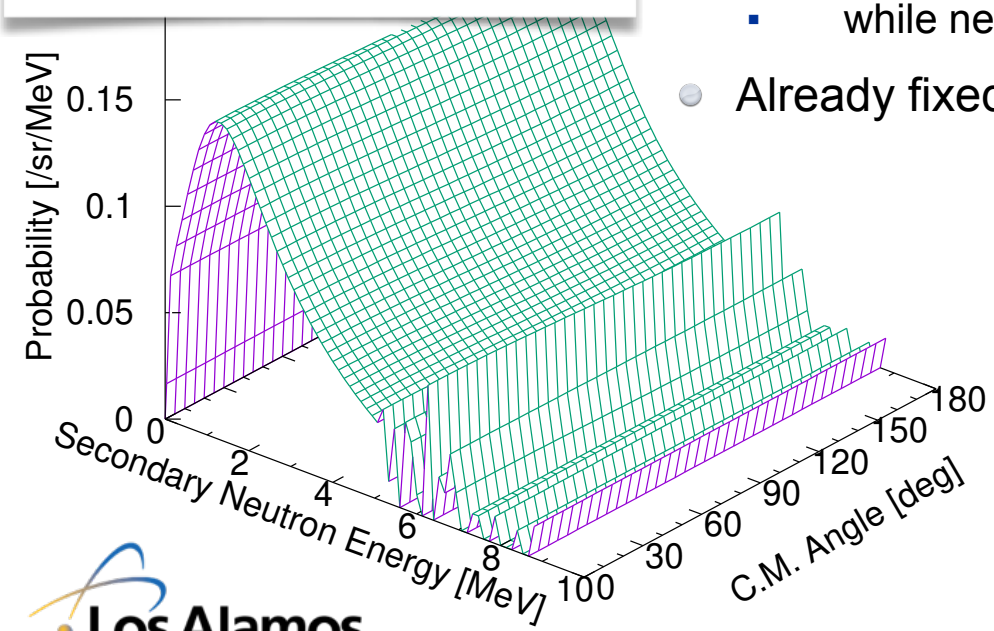
DOCUMENTATION SERIES OF THE IAEA NUCLEAR DATA SECTION

IAEA-NDS-0232
August, 2020

Processing of the Evaluated Photonuclear Data Library
(IAEA/PD-2019)

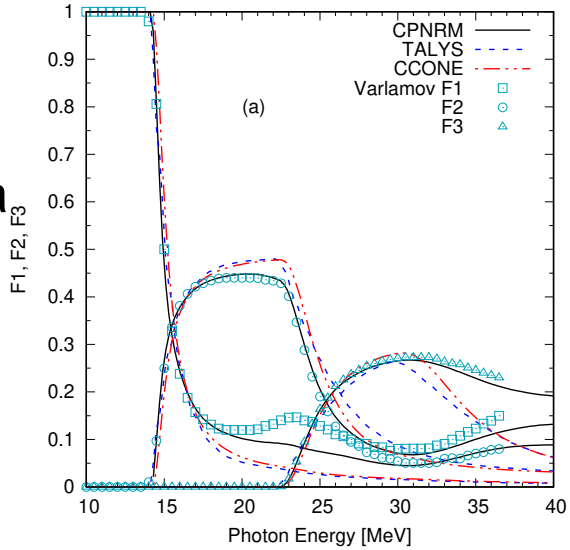
Hiroki KAWADA
Tokyo Institute of Technology

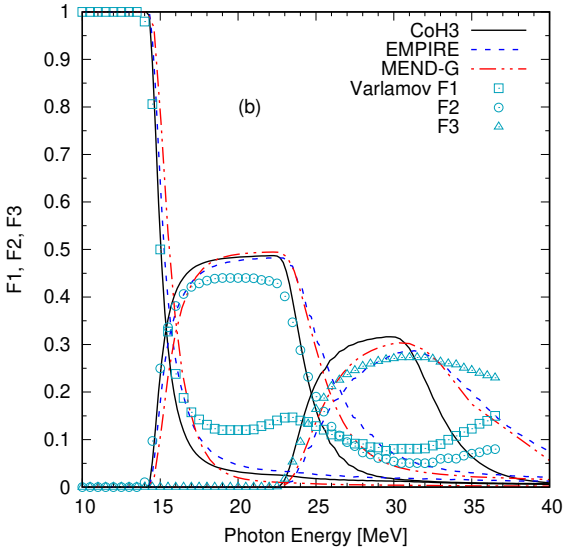
- NJOY problem reported in IAEA-NDS-0232
  - Angular distribution of secondary particles not correctly handled
  - This was probably caused by the data format in IAEA1999
    - Evaluation performed with the GNASH code
    - Pre-equilibrium angular distributions given by Kalbach's systematics
    - NJOY implicitly assumes Kalbach's parameters are given,
    - while new evaluations give the Legendre coefficients
  - Already fixed by W. Haek (LANL), and updated NJOY available



Need More Development in Theories

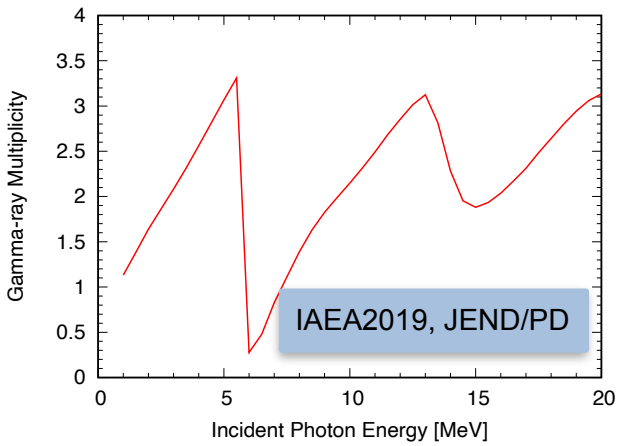
- R-matrix analysis, if possible, including photon channels
- Better GDR parameters predicted by nuclear structure theories, such as QRPA or FAM, when experimental data are unavailable (Sasaki, arXiv:2202.13214)
- High energy photon reactions still uncertain
  - Pre-equilibrium process for photon-induced reaction still uncertain
    - angular distributions by mimicking neutron-induced reaction
  - Quasi-deuteron cross section parameterized by Chadwick adopted all the codes
    - photo-absorption cross sections identical at higher energies
- Evaluated experimental data include model calculation
  - Correction factor depends on the model employed
  - This may cause some uncertainties if evaluation performed based on the corrected data

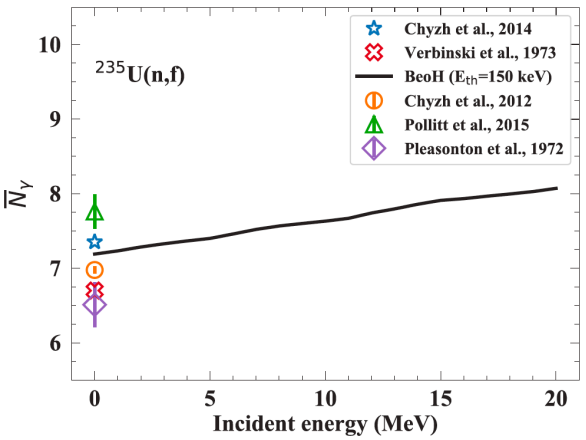




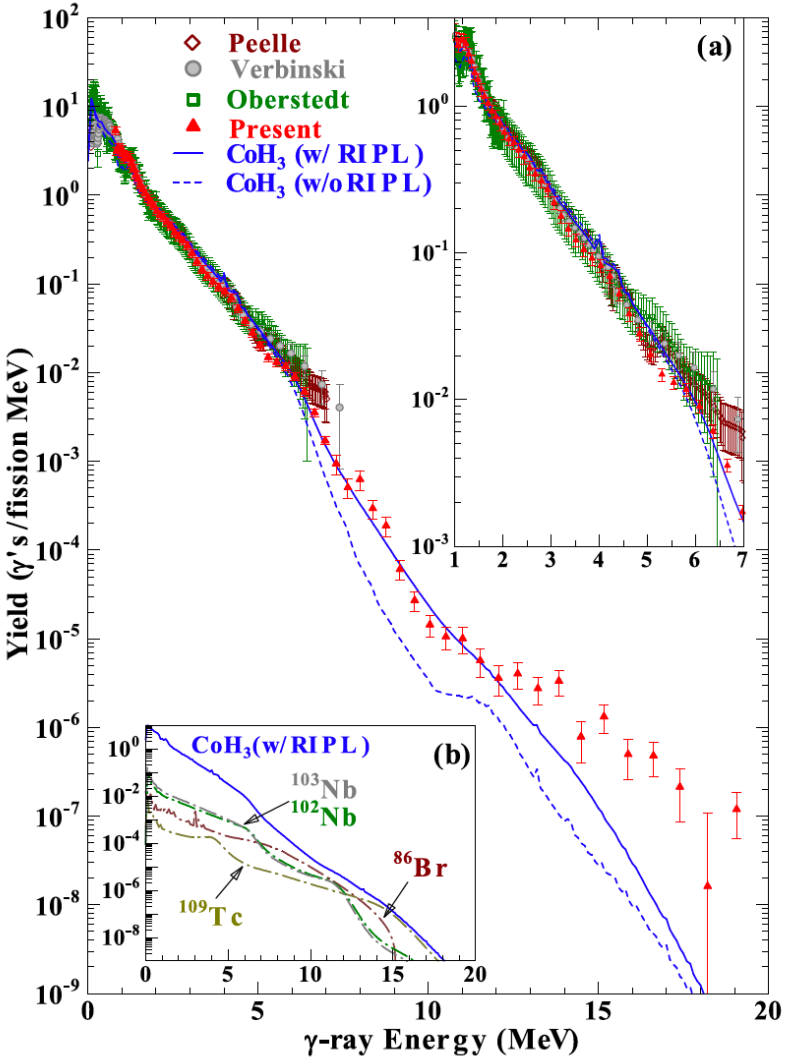
Missing Photo-Fission Gamma Production

- Prompt fission neutron spectrum given, However, MF6/MT5 for ZAP = 0 includes channels other than fission only
  - Fission gamma multiplicities should be ~ 7
- LANL model, published in PRC by Lovell et al., is able to produce the fission gamma-rays, at least up to 20 MeV





A.E. Lovell, PRC 103, 014615 (2021)



H. Makii, PRC 100, 044610 (2019)

Concluding Remarks

- IAEA 2019 is the most updated photonuclear data library
  - International effort, evaluated by multiple institutes
  - Model-calculation-based evaluations, which include NewSUBARU data
  - GDR parameters compiled by Plujko et al. tabulated in the report
- Deficiencies in theoretical modeling
  - R-matrix for light elements
  - Pre-equilibrium process for photon-induced reactions
  - Angular distributions for secondary neutrons, protons, etc.
  - Photo-fission needs more work, both theory development and experimental data
    - prompt and delayed neutron energy spectra and multiplicities
    - prompt fission gamma