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Title: 95Mo neutron capture and transmission final results

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^{95}Mo neutron capture and transmission final results¹

Paul Koehler

Presented at the NCSP TPR, February 23, 2023

Motivation and Background

- Poor performance of criticality benchmarks containing Mo²
- ⁹⁵Mo is a stable fission product and primary neutron absorbing isotope in ^{nat}Mo
- Criticality safety interest is for fission product credit for transport cases, irradiated fuel storage, and reprocessing plants³
- Neutron capture resonance integral is dominated by 45-eV resonance and latest evaluation⁴ reduced the capture kernel for this resonance, to level inconsistent with most previously published data, to yield better performance with criticality benchmarks
- Hence, new data were requested⁵
- Had very high quality data from nuclear astrophysics program at ORELA
Were never finalized and sent to EXFOR because funding was abruptly cut
- NCSP stepped in to make it possible to finalize the data and analysis and send the results to NNDC and IRSN (Luiz Leal) for incorporation into EXFOR and a new evaluation

Improvements Compared to Previous Work

- Substantially higher precision than previous data
- Very small change to data acquisition system (~1 wire/module) and replay program (~3 lines of code) and several months of extra analysis led to enormous increase in spin/parity information

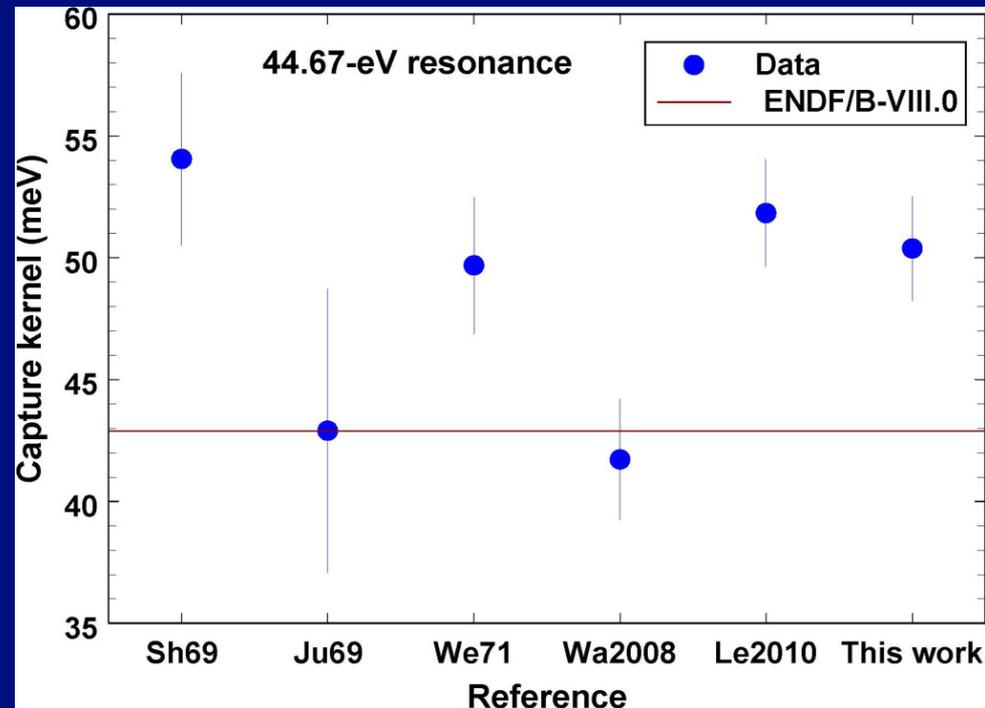
Extension of technique pioneered in Ref. 6

Any neutron capture setup with more than one detector could do similar work

- Observed resonances, 108 \rightarrow 314
- Firm J^π assignments, 32 \rightarrow 261
- Firm J^π and Γ_γ , 11 \rightarrow 261
- D_0 , S_0 , $\langle \Gamma_\gamma \rangle$, and Γ_n and Γ_γ distributions for all 6 s- and p-wave J^π 's

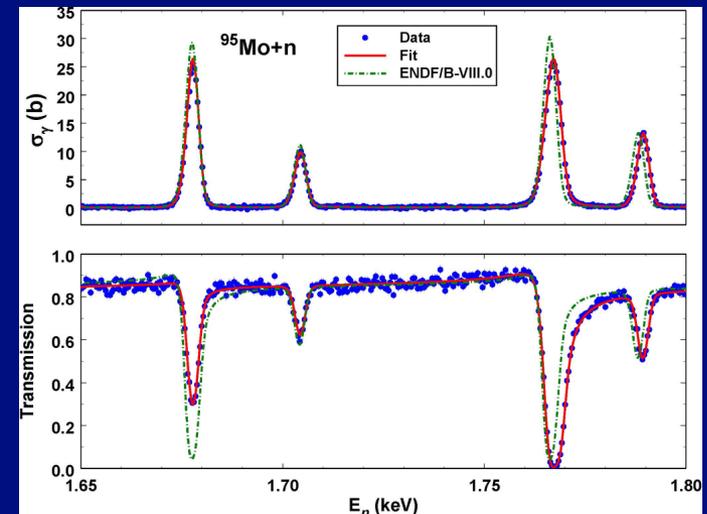
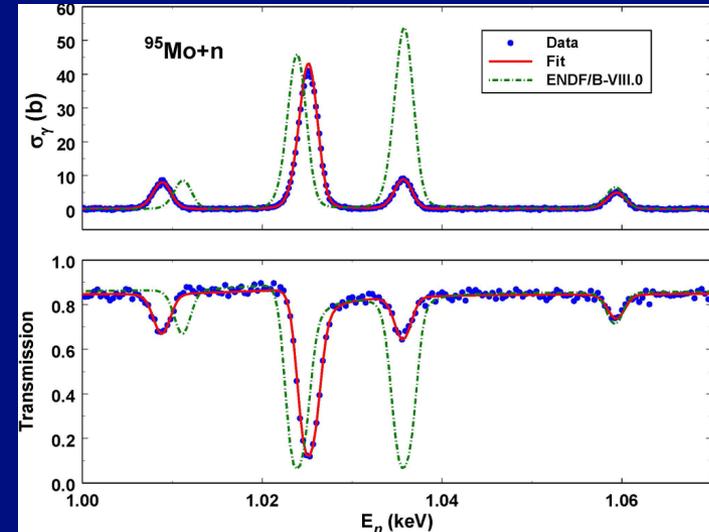
Main Direct Impact for NCSP

- ENDF/B-VIII.0⁴ solution to the integral benchmark discrepancy (reducing the capture kernel for the 44.67-eV resonance) is ruled out with high confidence ($z = 3.5 - 5.7$) by the data^{1,7-9}
- Only data with which ENDF/B-VIII.0 agrees are the two most limited sets^{10,11} with only 2 and 4 resonances reported
- Other resonances in these two references^{10,11} also are systematically smaller than the present work¹



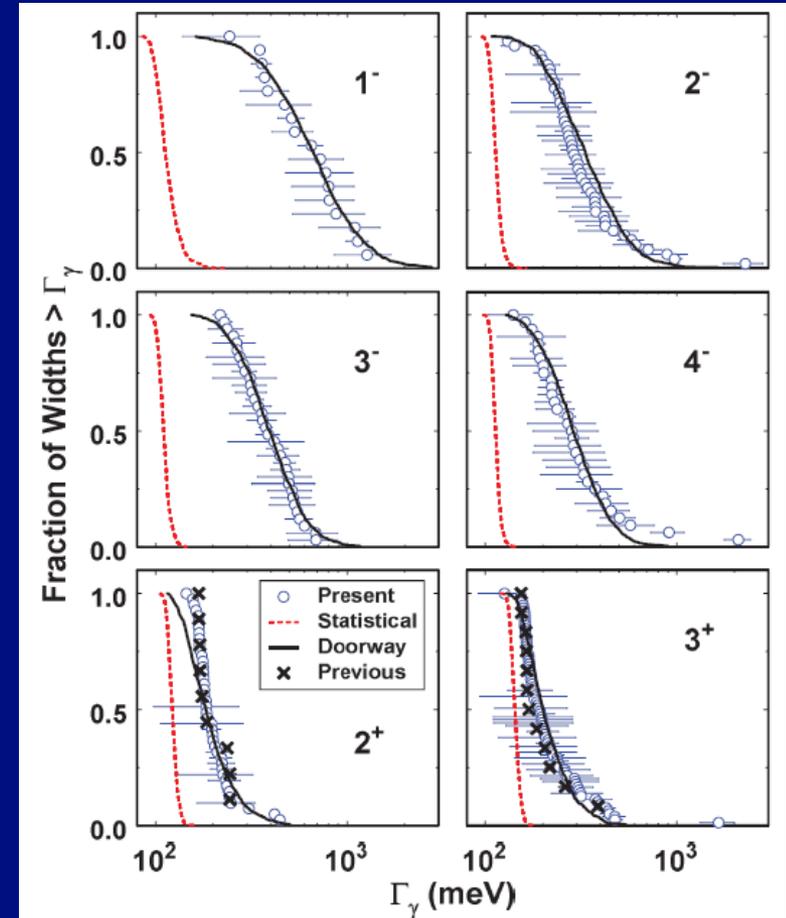
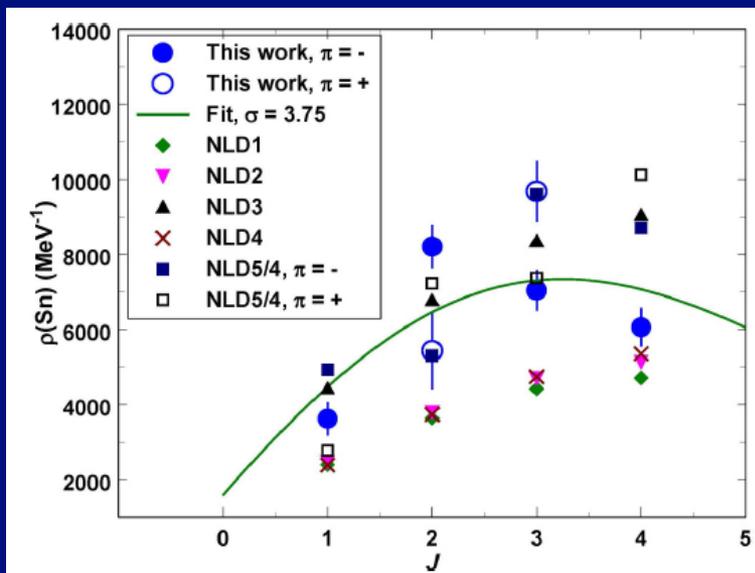
Further Comparisons to ENDF/B-VIII.0

- 56 resonances in ENDF, 314 in the present work
- 43 of 56 J values in ENDF consistent with the present work
- Γ_γ values in ENDF mostly fixed at two values according to parity, compared to 261 Γ_γ 's fitted in the present work
- ENDF neutron widths generally in poor agreement with the present work
- ENDF S_0 and D_0 values within uncertainties of the present work, but $\langle \Gamma_\gamma \rangle$ in sharp disagreement (9σ)
- ENDF has the wrong spin for the negative energy resonance
- ENDF capture resonance integral (104.4 b) substantially smaller than the present work (120.2 ± 1 b)



Comparison to Nuclear Models

- Present data revealed extreme non-statistical effects in gamma decay of ^{95}Mo neutron resonances¹² inconsistent with models
- Spin-cutoff parameter extracted from the data is within the range assumed in many models, but shape and parity dependence of data disagree with models (Taly¹³ shown in fig. below)



Conclusions

- ENDF/B-VIII.0 solution to the Mo integral benchmark discrepancy is ruled out with high confidence by the data
- Very small changes to the data acquisition hardware and software led to very large improvements in the resonance parameters extracted from the data

Any neutron capture apparatus with more than one detector could benefit from these changes

Perhaps machine-learning techniques could lead to further improvements

- The more extensive and detailed neutron resonance data from the present work made more stringent tests of nuclear models possible and several important problems with the models were revealed

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