Progress in resonance evaluations of gadolinium for the Nuclear Criticality Safety Program (NCSP)

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Washington, DC

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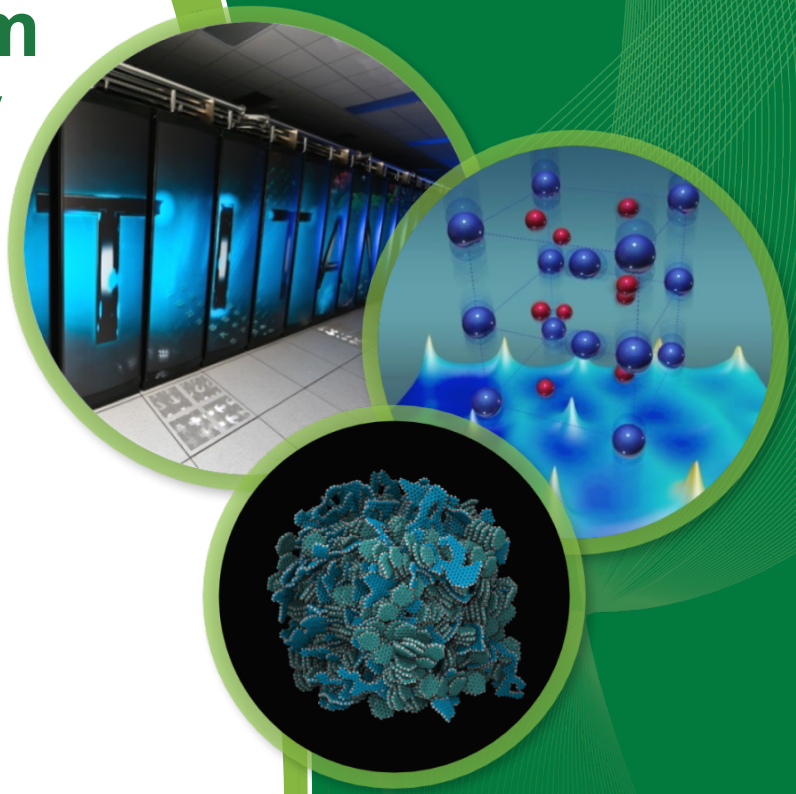

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for the US Department of Energy

OAK RIDGE National Laboratory

Gadolinium plays a significant role in the nuclear industry

- Emergency shutdown
- Burnable reactor poison
- Tumor treatment

Naturally occurring abundances for the isotopes of gadolinium and thermal capture cross-section values from *Atlas of Neutron Resonances*

Isotope	Abundance (%)	Thermal capture cross section (b)
^{152}Gd	0.20	735 +/- 20
^{154}Gd	2.18	85 +/- 12
^{155}Gd	14.80	60 900 +/- 500
^{156}Gd	20.47	1.8 +/- 0.7
^{157}Gd	15.65	254 000 +/- 815
^{158}Gd	24.84	2.2 +/- 0.2
^{160}Gd	21.86	1.4 +/- 0.3

Largest thermal-neutron cross section of all naturally occurring isotopes!

History of gadolinium resonance evaluations

- ENDF/B-VII.0 resonance evaluation produced by WPEC SG23: International Library of Fission Product Evaluations
- ENDF/B-VII.0 evaluation is discrepant with average cross section measurements from Karlsruhe
- Experimental measurements from the RPI Gaerttner LINAC Center suggest **discrepancies of up to 9%** in the thermal cross section values with respect to the current ENDF/B-VII.1 evaluation

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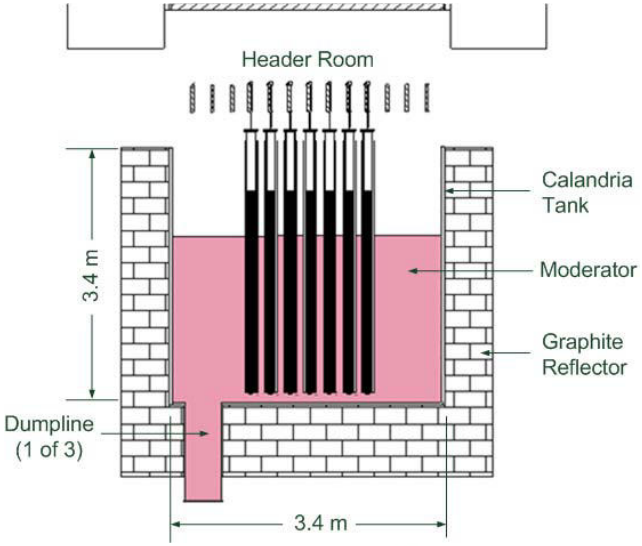
One prominent case for re-evaluation

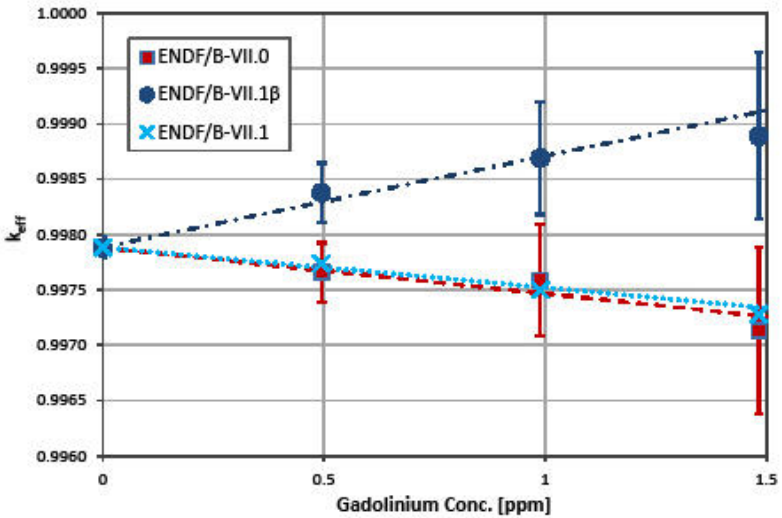
- An Atomic Energy of Canada Ltd. (AECL) study conducted in the Zero Energy Deuterium (ZED-2) critical facility measured k_{eff} vs Gd concentration

- Results indicate **under-prediction** of the capture cross section in the **beta** release and **over-prediction** in **ENDF/B-VII.1**

ZED-2 reactor layout, Ref. 4



ZED-2 calculated k_{eff} for different nuclear data libraries, Ref. 4



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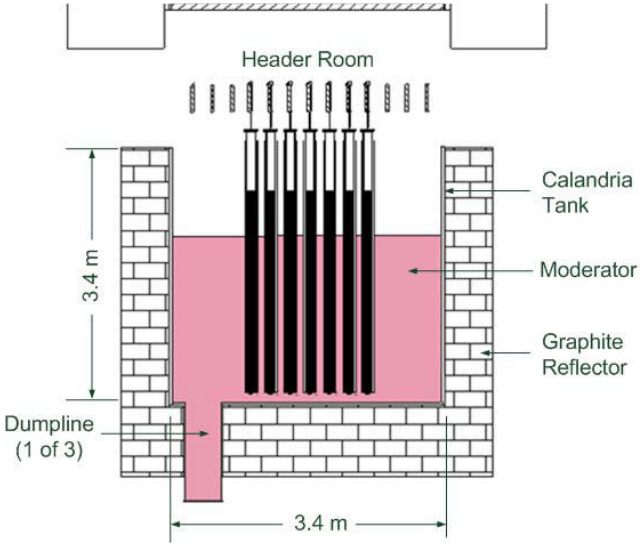

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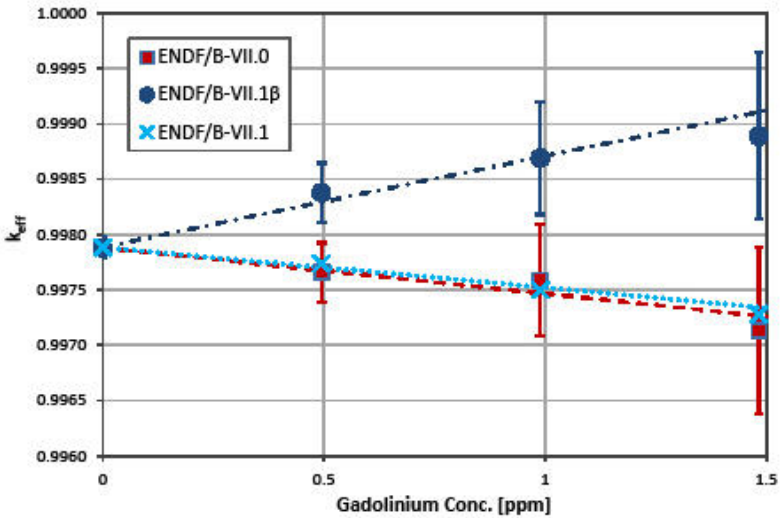
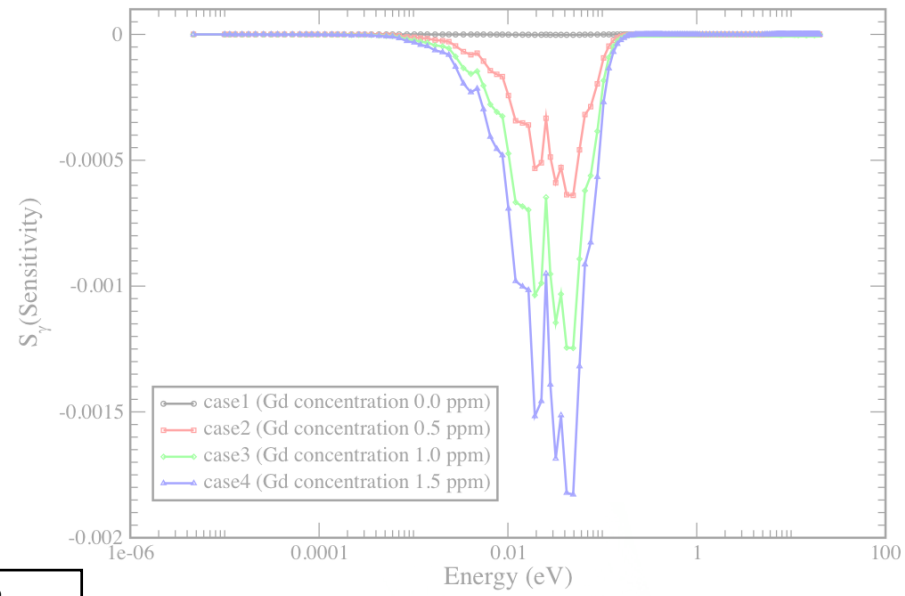


Re-evaluation of the isotopes of gadolinium

- ORNL and IRSN are collaborating on the evaluation
- The completed new evaluation will be proposed for inclusion in the next release **after** ENDF/B-VIII.0
- Multiple sets of differential experimental data will be evaluated, including new measurements

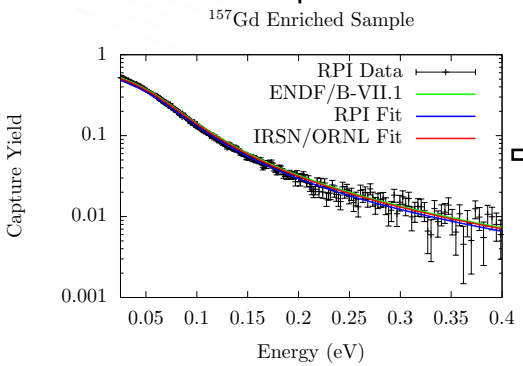
Application of the SAMINT methodology for simultaneous differential and integral data

Calculated sensitivity profile for gadolinium

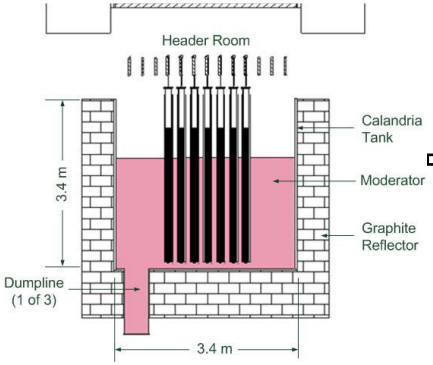


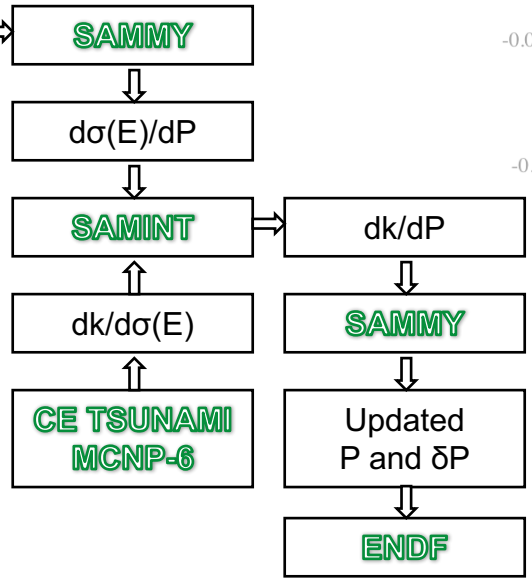
SAMINT flowchart

Differential experimental data



Integral experimental data





P = all resonance parameters:
E_λ, Γ_γ , Γ_n , Γ_f , etc.

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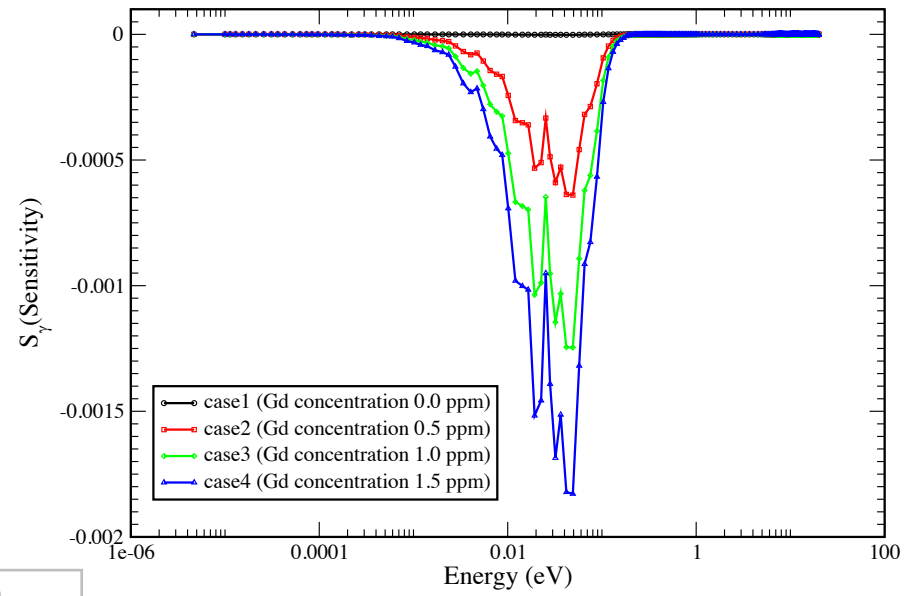

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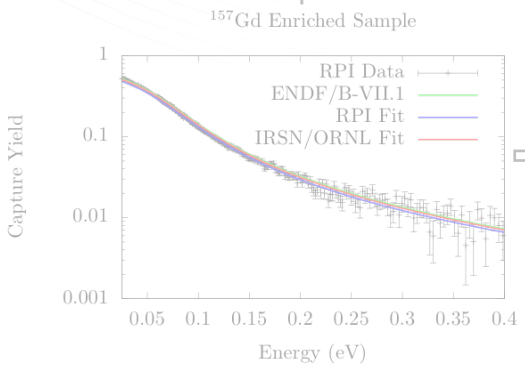

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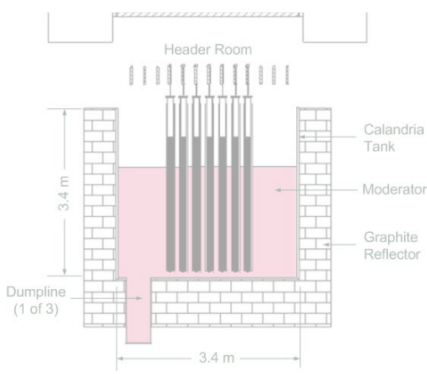

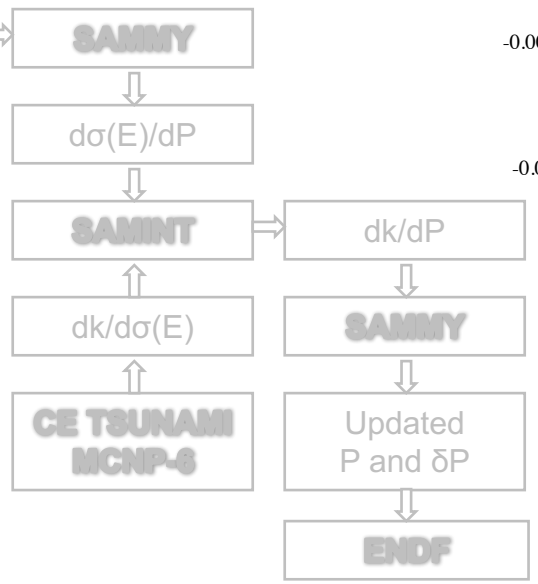

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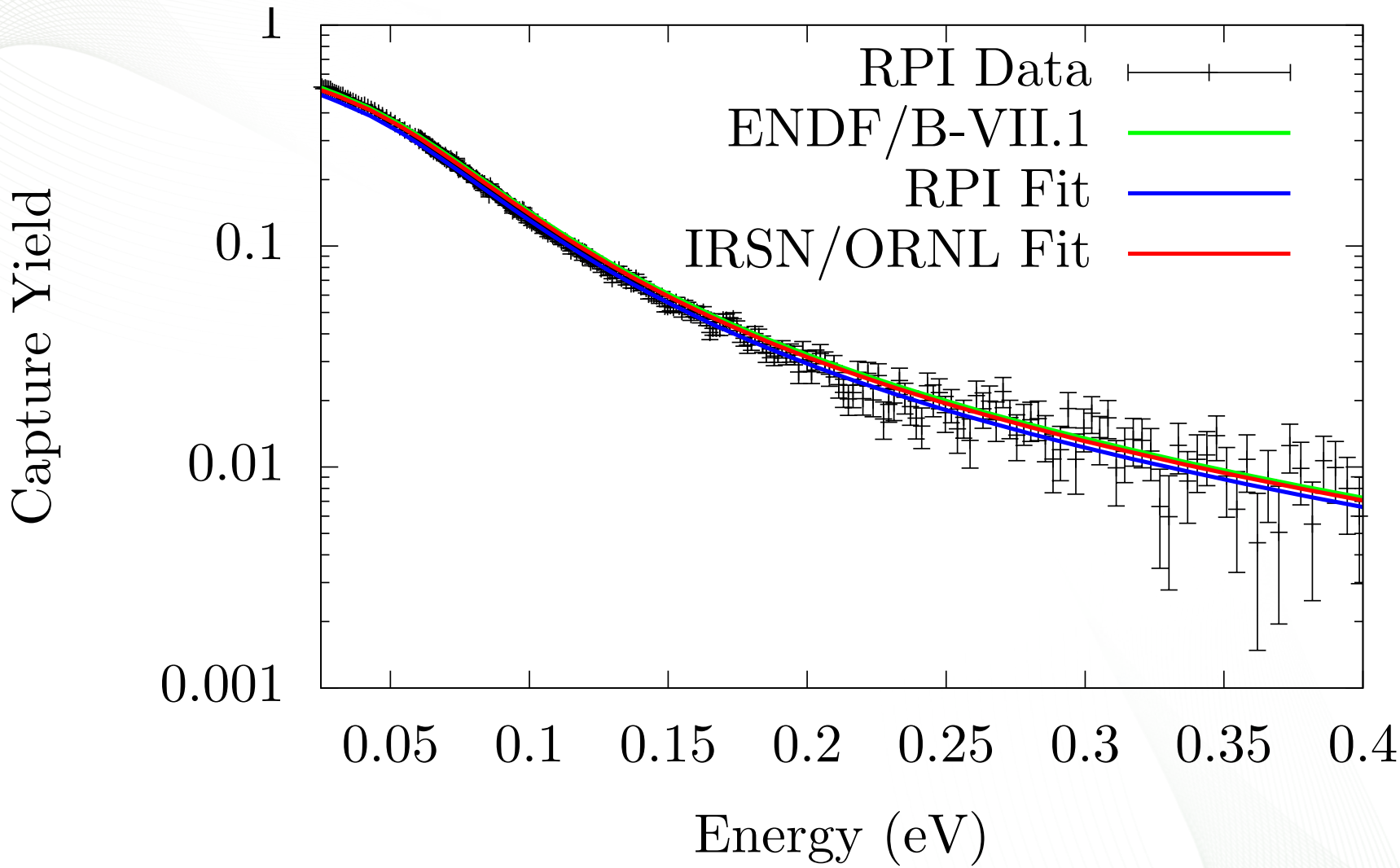
^{157}Gd enriched sample



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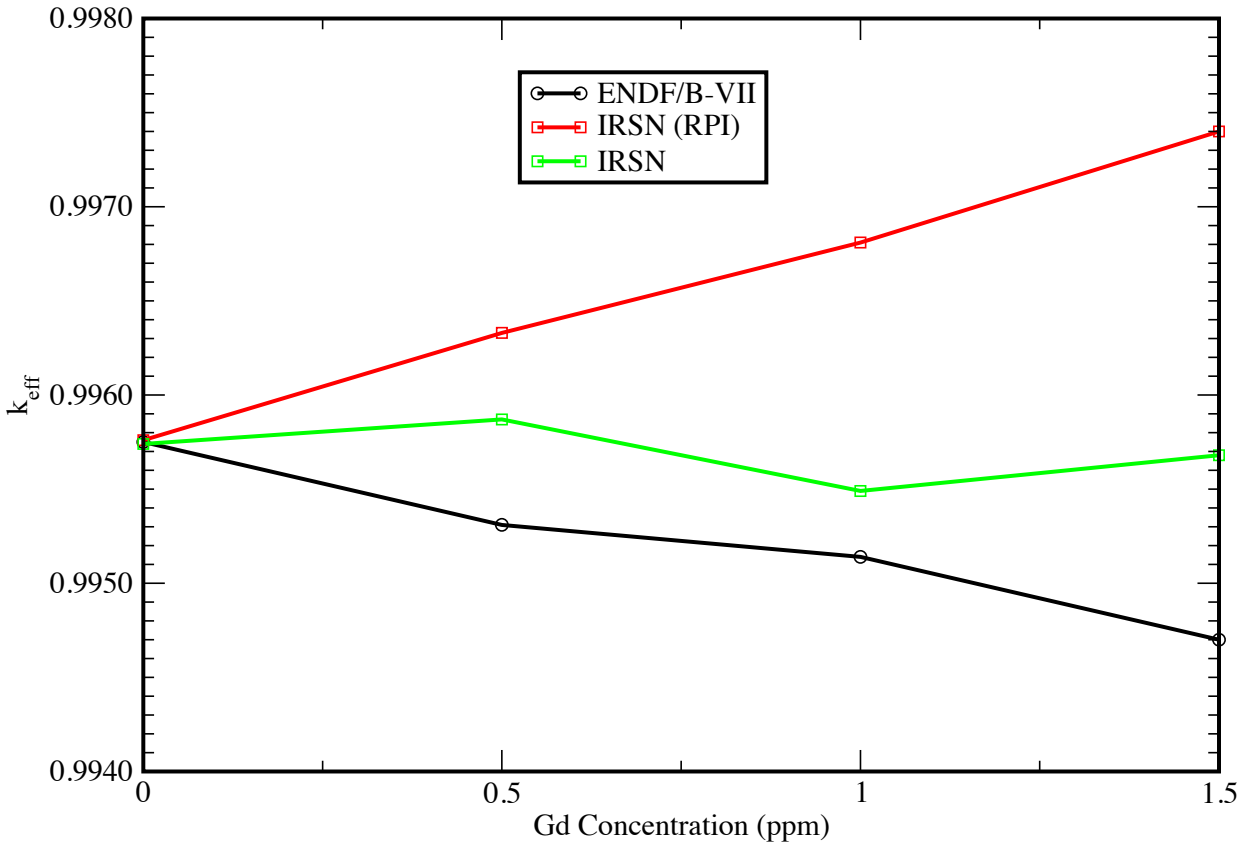

Cross-isotope covariance

- Uncertainty information of the resonance parameters of the individual isotopes is tied together with cross-isotope covariance through the analysis of **natural samples**
- A full resonance parameter covariance matrix is necessary to accurately reflect the state of knowledge of the cross section simultaneously for:
  - Individual isotopes,

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  - Their combination in the cross section of the natural element

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Correlated uncertainties

10% uncertainty in experimental measurement
of a natural sample

does not imply

10% uncertainty in the cross section of the individual isotopes

Only through cross-isotope covariances can the evaluator accurately reflect the fact that the

cross section for the natural element
(the sum of the individual isotopes)

can be better known
(i.e., it can have a smaller variance)

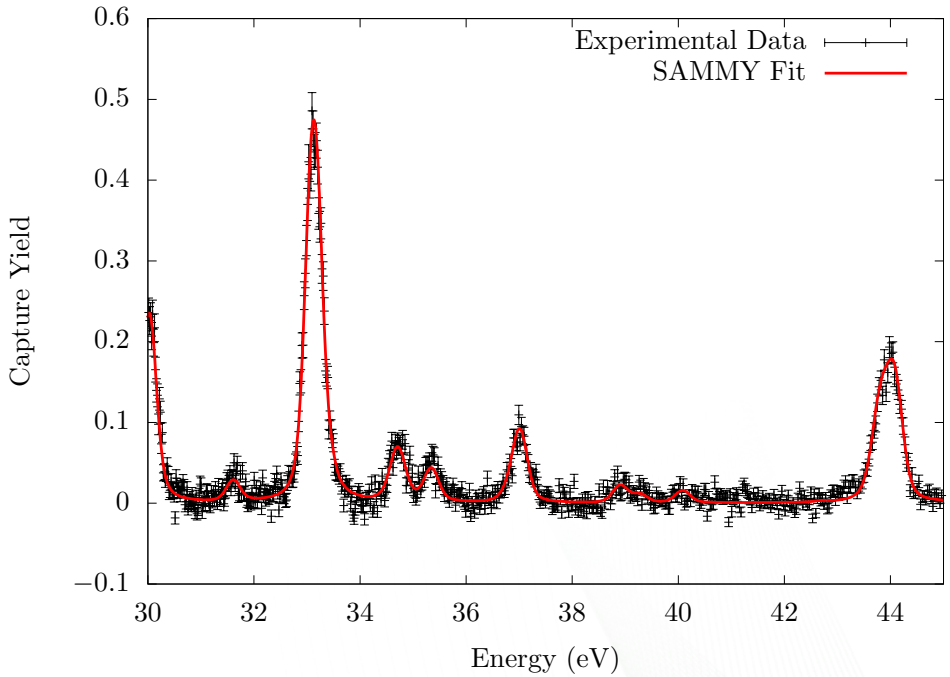
than each of the

cross sections of any of the individual isotopes

Demonstration of the impact of cross-isotope covariance

- Only statistical uncertainty is considered in this demonstration
- All systematic sources of uncertainty will be rigorously treated in the final covariance evaluation

SAMMY fit of RPI data



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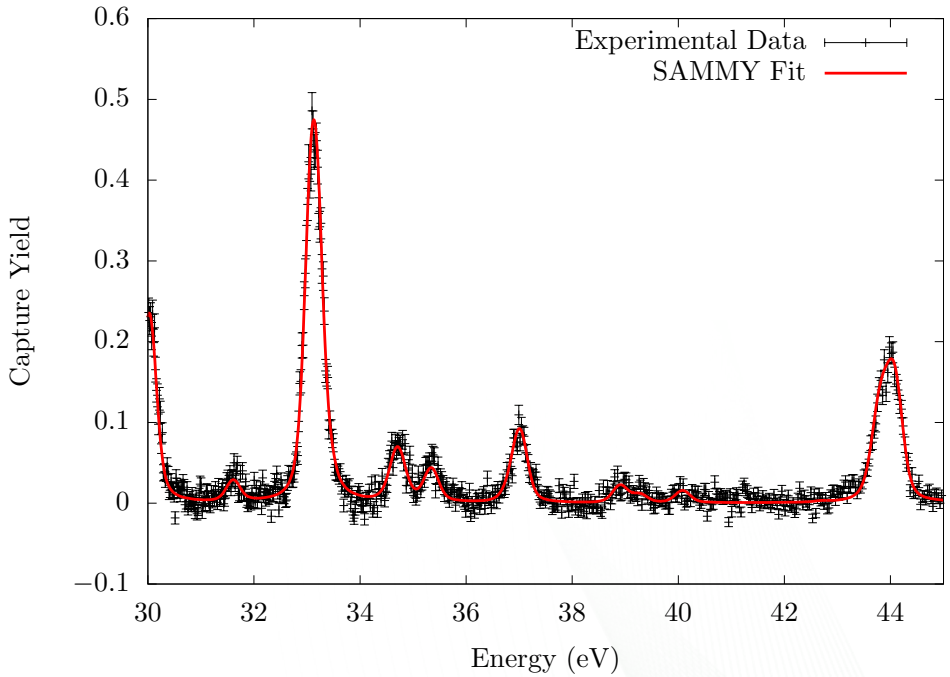

Resonances of gadolinium isotopes in the energy region of 30 to 45 eV

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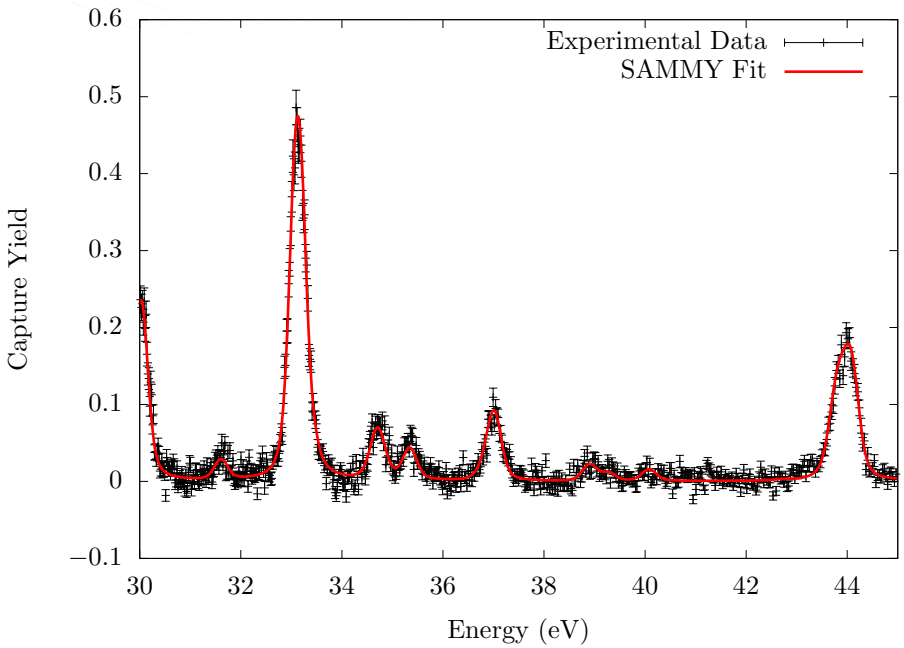
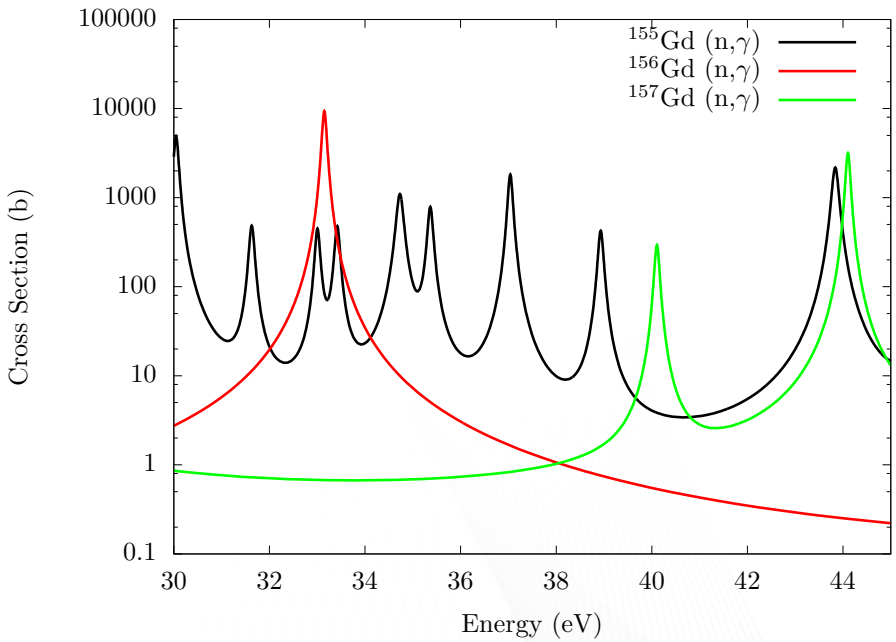
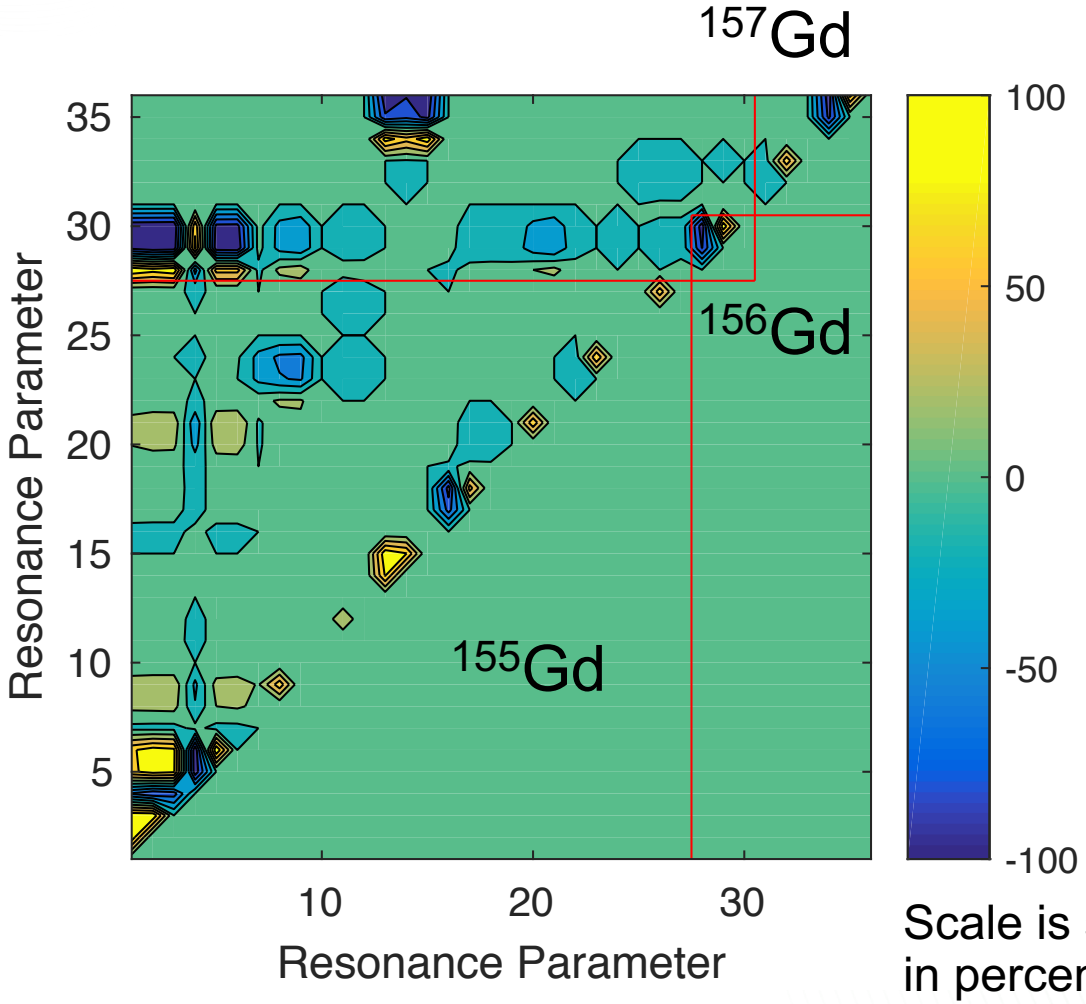


Gadolinium capture cross section

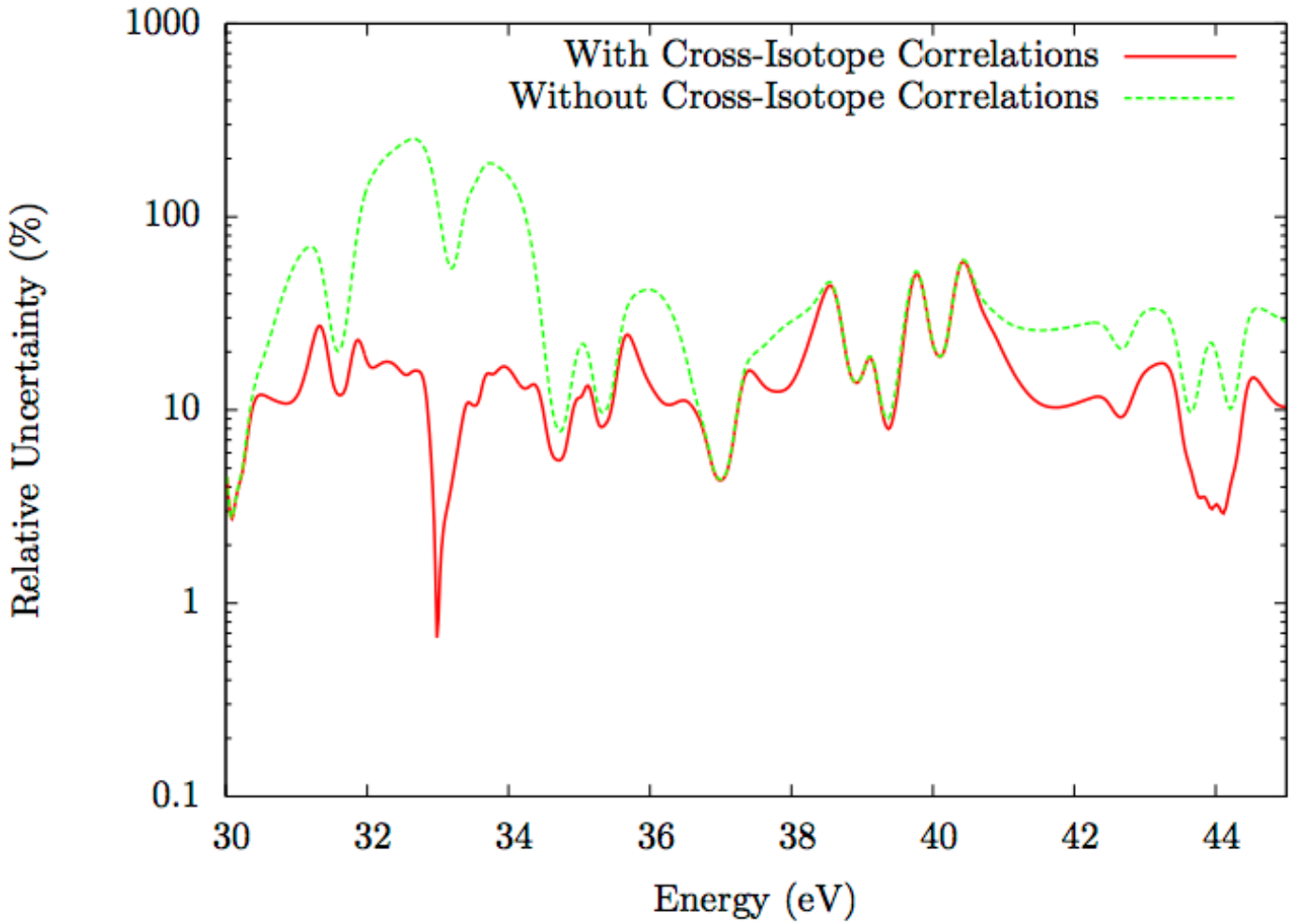


Upper triangular portion of the joint resonance parameter correlation matrix for resonances of ^{155}Gd, ^{156}Gd, and ^{157}Gd between 30 and 45 eV.



Scale is shown in percent

Cross-isotope correlations are usually not reported in general-purpose nuclear data libraries



Summary of re-evaluation of resonance region of gadolinium

- The new evaluation seeks to resolve some of the discrepancies between the experimentally measured data
- The new evaluation will deliver a covariance matrix with cross-isotope covariances that are a natural byproduct of the analysis of natural samples of gadolinium
- A full covariance matrix delivers a more accurate representation of the confidence in the evaluated cross sections and will enable more reliable propagated uncertainty studies for systems containing gadolinium
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