International Atomic Energy Agency

Reaction Yield Divided by Areal Density

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Resonance Analysis

Resonance parameters are adjusted so that they describe experimental observables.

Reich-Moore Formalism [2]

The Reich-Moore formalism involves summation over levels and a matrix inversion with respect to channels.

The matrix (1-*RL*) is partitioned into a 2×2 matrix, each element of which leads to a definition on the matrix

$$K_{cc'} = \frac{i}{2}\sum_{\lambda}\frac{\Gamma_{\lambda c}^{1/2}\Gamma_{\lambda c'}^{1/2}}{E_{\lambda} - E - \frac{i}{2}\Gamma_{\lambda\gamma}}$$

The neutron fission cross section can be expressed by:

$$\sigma_{nf} = \sum_{c=2}^{I+1} 4\pi\lambda_n^2 g\left|(1 - K_{nC})^{-1}\right|^2$$

where I = number of fission channels

Resonance Analysis

Correction for experimental effects

T, Y_{capt} etc. (uncorrected)

↓

T, Y_{capt} etc. (corrected)
(in EXFOR)

↓ Least-squares analysis

(E_r, Γ_n, Γ_γ)

T, Y_{capt} etc. (uncorrected)

↓

T, Y_{capt} etc. (corrected)

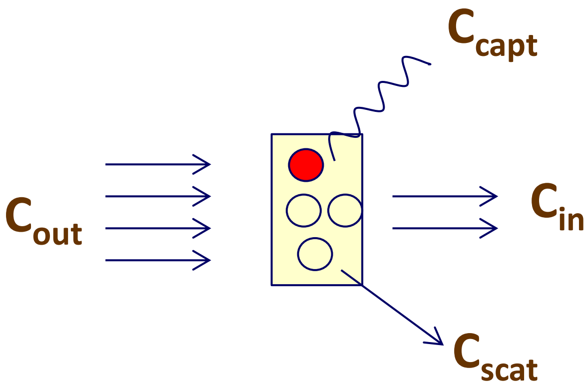
↓ Further correction

σ_{tot}, σ_{capt} etc.
(in EXFOR)

↓ Least-squares analysis

(E_r, Γ_n, Γ_γ)

Transmission (TRN) and Reaction Yield (RYL)



Transmission

$T = \exp(-n\langle\sigma_{tot}\rangle)$

$= N\, C_{in} / C_{out}$

Reaction yield for channel x

$Y_x = [1 - \exp(-n\langle\sigma_{tot}\rangle)] \cdot (\langle\sigma_x\rangle/\langle\sigma_{tot}\rangle) + Y_m$

$= N\, C_x/\phi + Y_m$

C: net count, ϕ: beam flux
n: areal sample density
N: normalization constant
$\langle\sigma\rangle$: Doppler broadened cross section
Y_m: Yield due to multiple interaction

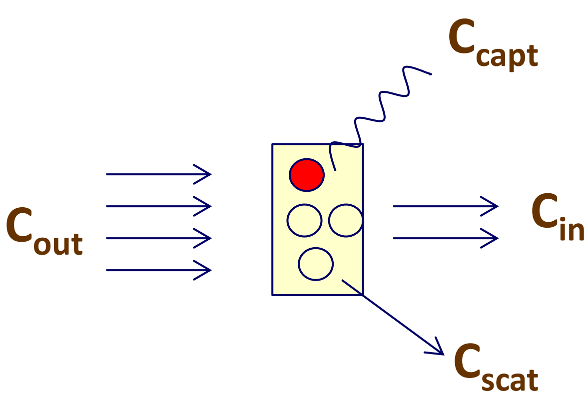
Transmission and Reaction Yield

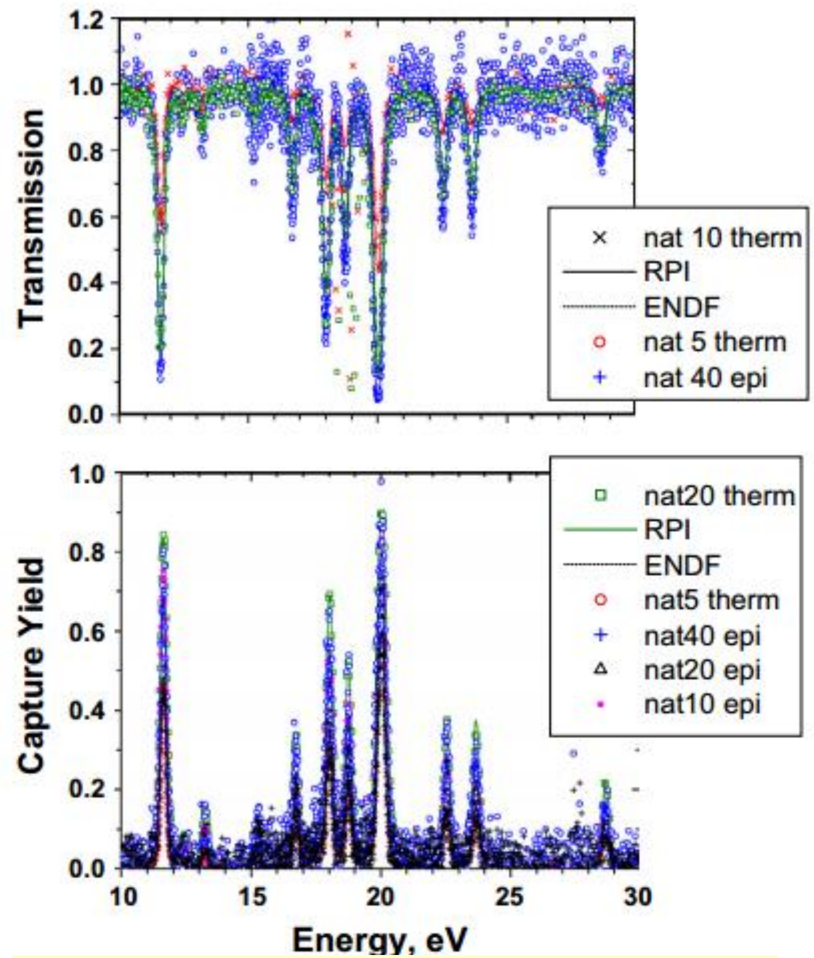
Transmission (dimensionless)

$T = \exp(-n\langle\sigma_{tot}\rangle)$

Reaction yield for channel x (dimensionless)

$Y_x = [1 - \exp(-n\langle\sigma_{tot}\rangle)] \cdot (\langle\sigma_x\rangle/\langle\sigma_{tot}\rangle) + Y_m$



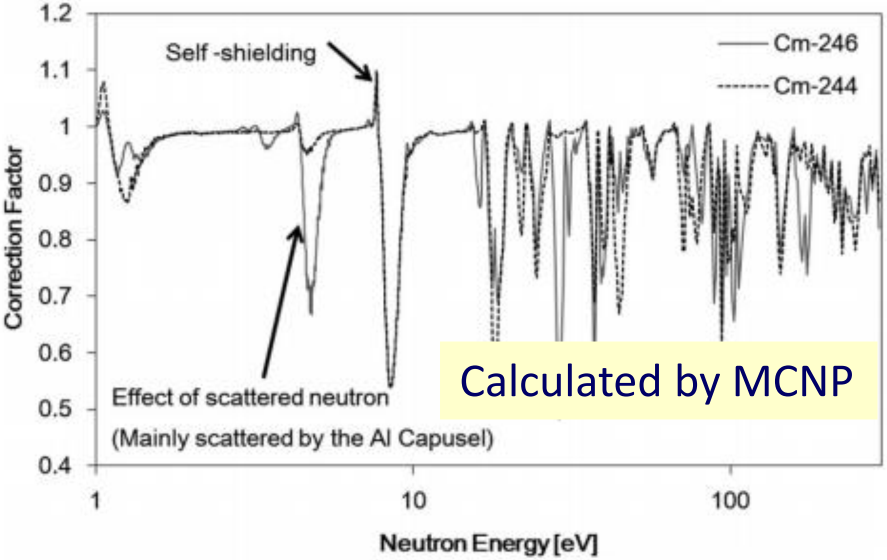


Eu+n measured at RPI
(C.Leinweber+,J,ANE,69,74,2014)

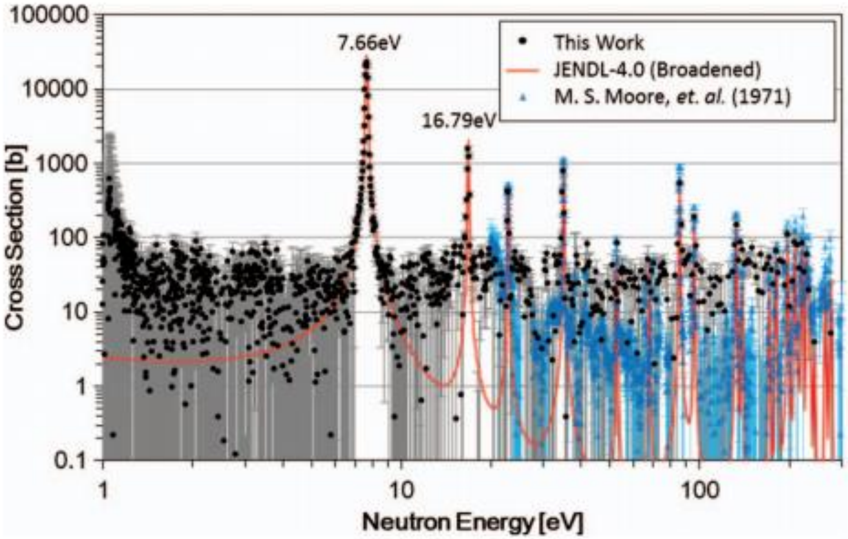
Reaction Cross Section (SIG)

Sometimes reaction yields are converted to the reaction cross sections by the experimentalist:

$Y_x = [1 - \exp(-n\langle\sigma_{tot}\rangle)] \cdot (\langle\sigma_x\rangle/\langle\sigma_{tot}\rangle) + Y_m \rightarrow \langle\sigma_x\rangle = ...$



Calculated by MCNP



Cm+n at J-PARC
A. Kimura+, J,NST,49,708,2012

Reaction Yield and Cross Section

For a thin sample (i.e. neutron interact with nuclide one time at maximum),

$$Y_x = [1 - \exp(-n<\sigma_{tot}>)] \cdot (<\sigma_x>/<\sigma_{tot}>) + Y_m \sim n<\sigma_x>$$

(Y_x: dimensionless; n: atoms/barn)

Y_x/n is a quantity in barn, and some experimentalists adopt it as an expression (normalization) of the yield (even for thick samples).

This is a cross section not corrected for sample effects, namely raw cross section (,SIG,,RAW) according to LEXFOR.

LEXFOR (Feb. 2008) "Raw Data"

Reaction yields:

$$\langle y_r \rangle = \left\langle \left(1 - e^{-n\overline{\sigma_T}}\right) \frac{\overline{\sigma_r}}{\overline{\sigma_T}} + \sum_{i=1}^{\infty} y_{r,i} \right\rangle$$

where: <…> denotes resolution broadening

n is the sample thickness in nuclei/barn

σ_T and σ_r are the Doppler-broadened, abundance-weighted total and partial reaction cross sections, respectively

$y_{r,i}$ is the reaction yield from neutrons scattered i times before inducing the reaction of type r, *e.g.*, fission, scattering or radiative capture.

Note that the following simple relationship with the (broadened) cross section exists for thin samples $\left(n\langle\sigma_T\rangle << 1\right)$:

$$-\frac{1}{n}\ln\left\langle e^{-n\sigma_T}\right\rangle \cong \left\langle\overline{\sigma_T}\right\rangle; \quad \boxed{\frac{1}{n}\langle y_r\rangle \cong \left\langle\overline{\sigma_r}\right\rangle}$$

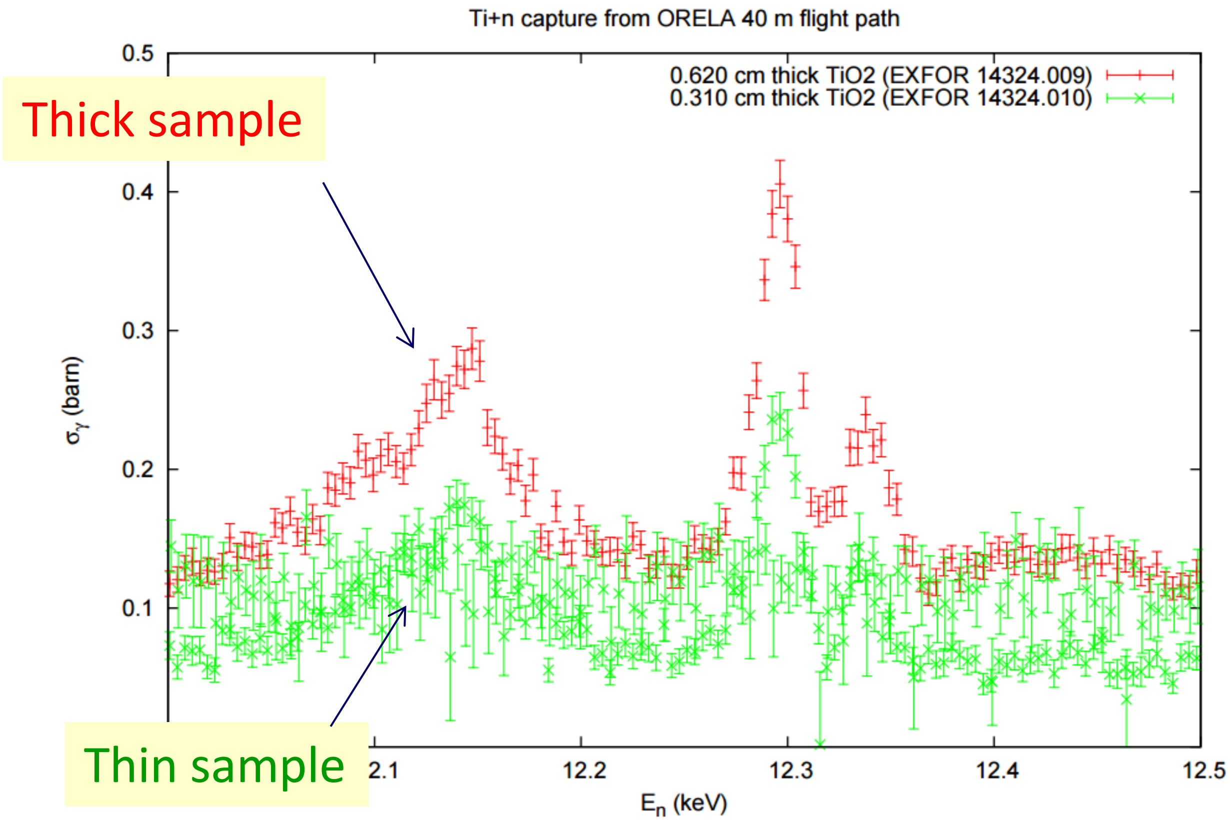
Data may be given as *counts* or as uncorrected cross sections in barns.

The data may be transmitted in EXFOR using the modifier `RAW` in `REACTION` SF8; it should always be explained in free text.

This part is missed in the current LEXFOR (my fault!)

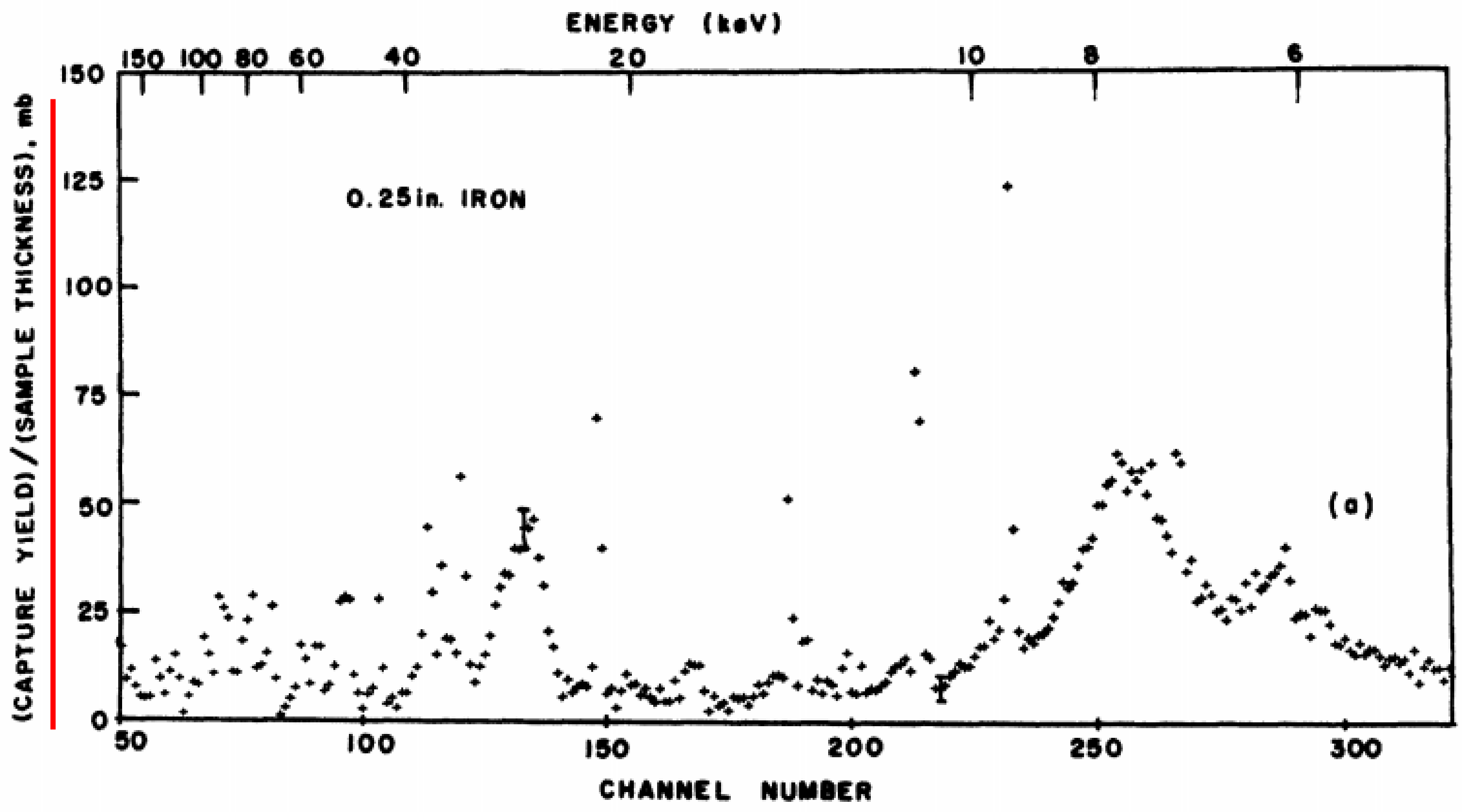
Finite Sample Thickness Effect

Capture yield divided by areal density by Klaus Guber et al.
("experimental cross section" in his terminology.)



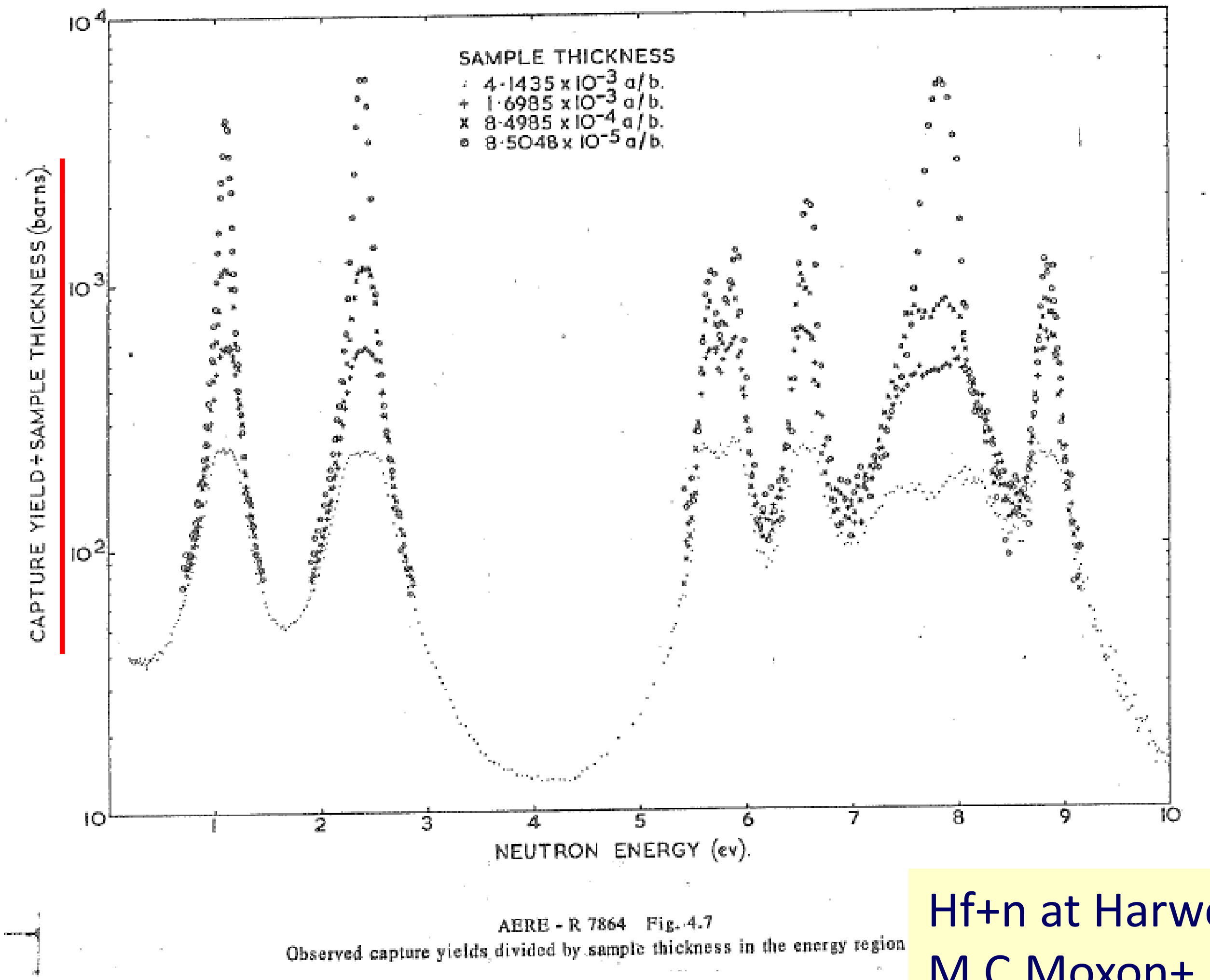
Can be used for R-matrix analysis only after corrections for sample effects

Capture Yield Divided by Areal Density (,SIG,,RAW)



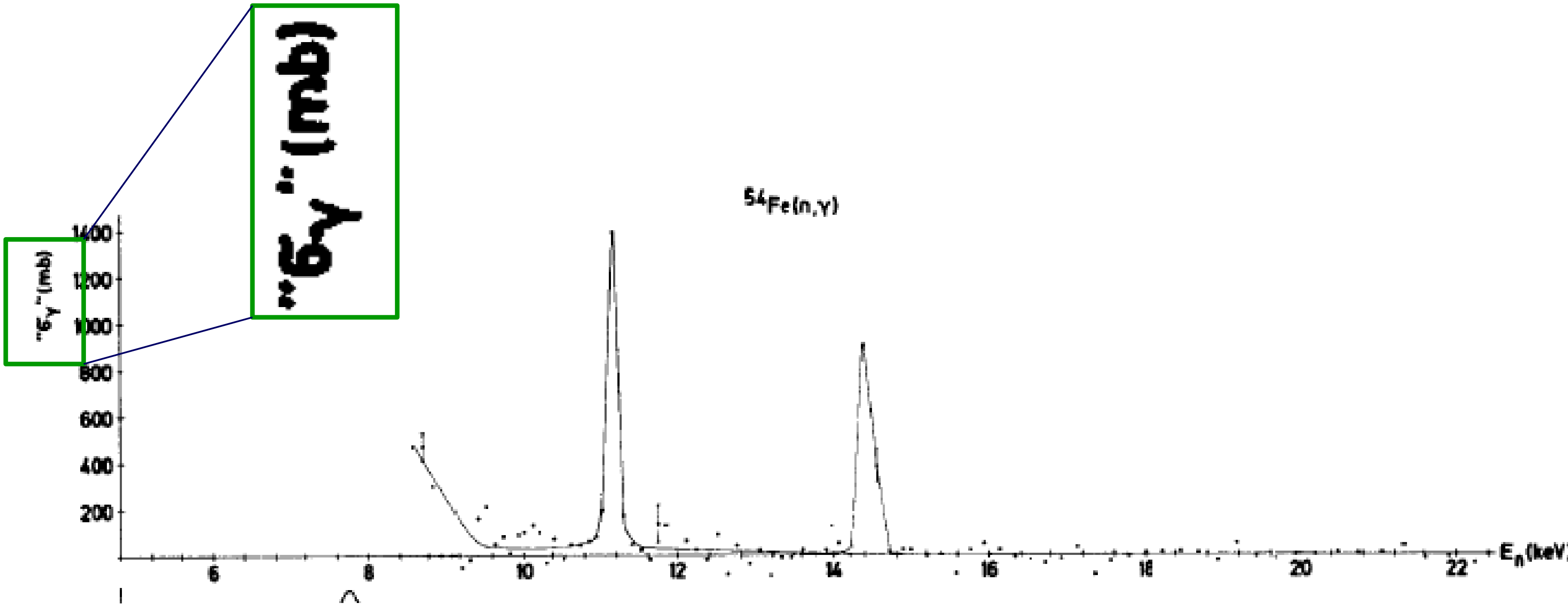
Fe+n at RPI (EXFOR 10001)
R.W.Hockenbury+,J,PR,178,1746,1960

Capture Yield Divided by Areal Density (,SIG,,RAW)



Hf+n at Harwell,
M.C.Moxon+,R,AERE-R-7864,1974

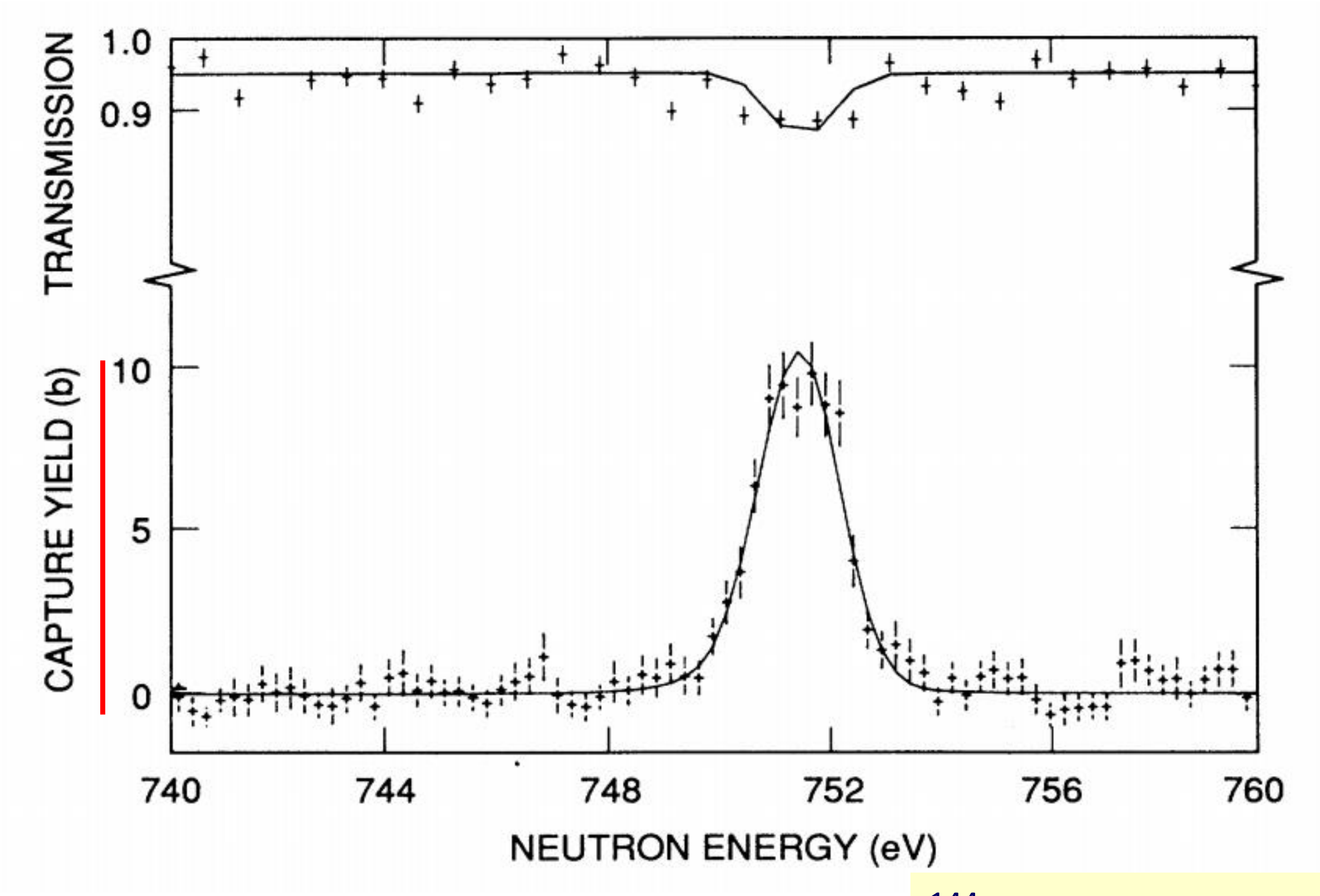
Capture Yield Divided by Areal Density (,SIG,,RAW)



Figs. 1–3. Top: ^{54}Fe capture yield divided by sample thickness. Centre: Resolution broadened, total ^{54}Fe computed from the *R*-matrix parameters. Bottom: The transmission data and *R*-matrix

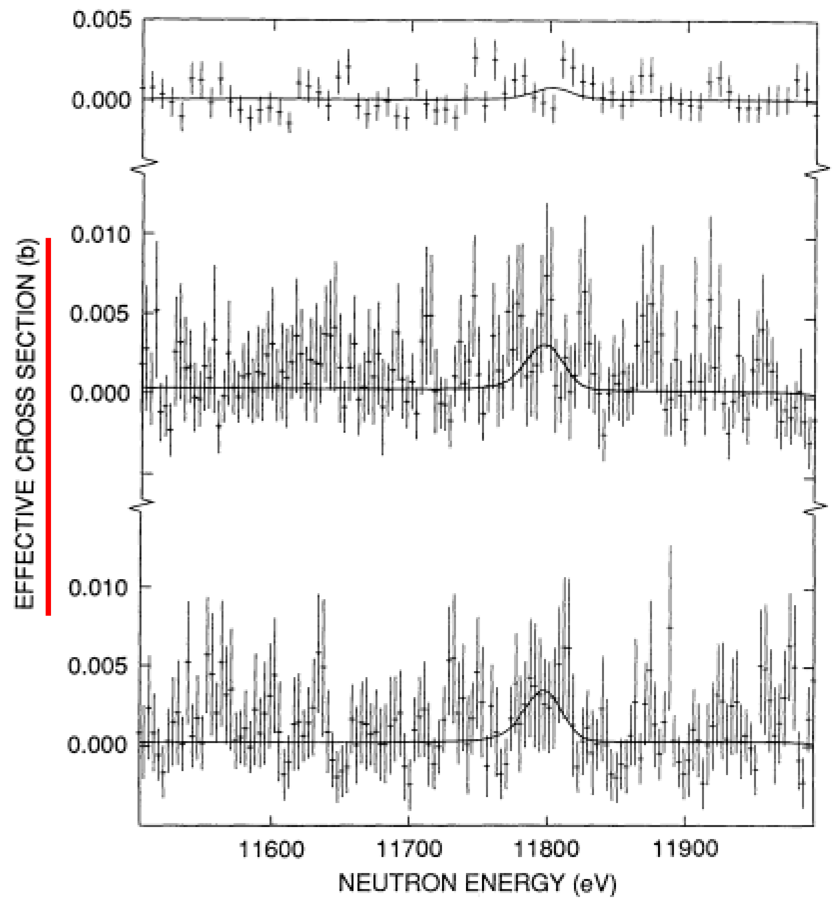
^{54}Fe+n at KFK,
H.Beer+,J,NP/A,240,29,1975

Capture Yield Divided by Areal Density (,SIG,,RAW)



^{144}Sm+n at ORELA,
R.L.Macklin+,J,PR/C,48,1120,1993

Capture Yield Divided by Areal Density (,SIG,,RAW)



^{12}C+n at ORELA,
R.L.Macklin,J,AJ,357,649,1990

Capture Yield Divided by Areal Density (,SIG,,RAW)

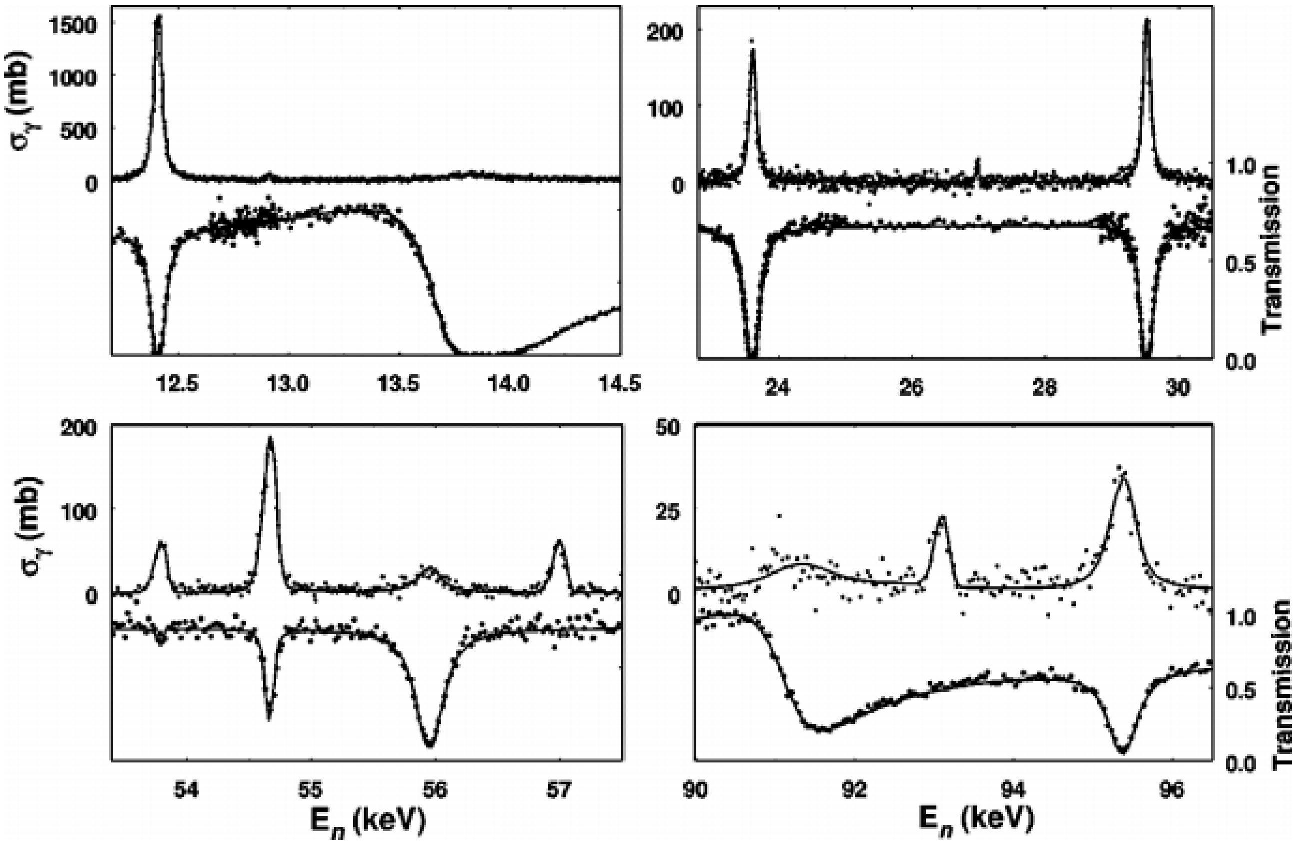


FIG. 2. Representative data (points) and SAMMY fits (solid curves) from our capture (top) and transmission (bottom) measurements on ^{88}Sr. The effective capture cross sections have not been corrected for finite-thickness effects. The corrections are included by the code SAMMY; hence, the fits represent the theoretical cross sections, calculated from the resonance parameters, after adjustment for these sample-dependent effects. The scales for the capture data are on the left of each plot, whereas the transmission scales are on the right.

^{88}Sr+n at ORELA,
P.E.Koehler+,J,PR/C,62,055803,2000

Capture Yield Divided by Areal Density (,SIG,,RAW)

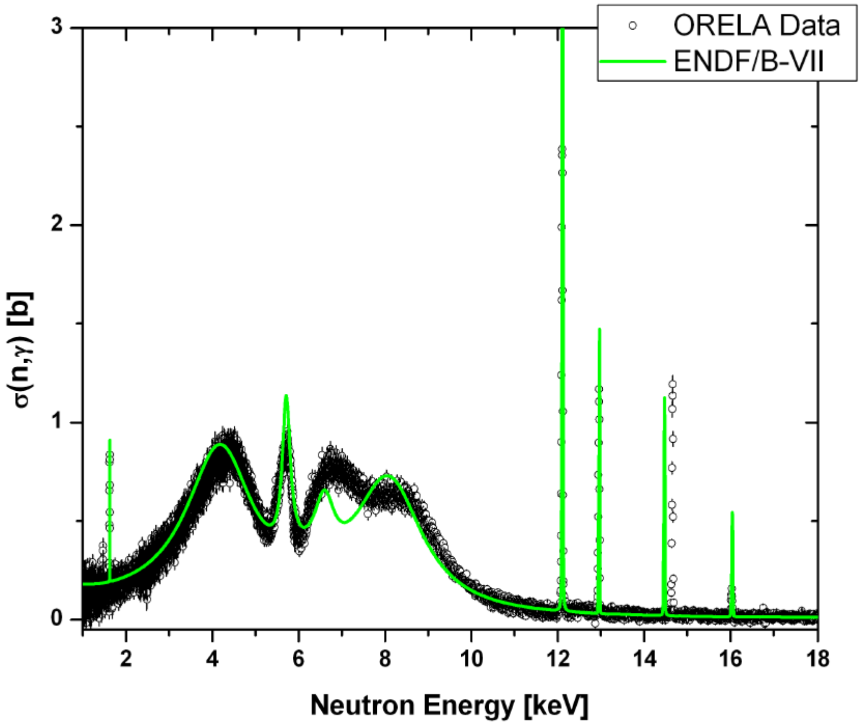


Fig. 4. (Color online) Neutron capture for ^{53}Cr oxide compared to ENDF/B-VII evaluation parameters.

"Experimental cross section" according to the author (K. Guber)

^{53}Cr+n at ORELA,
K.H.Guber+,J,KPS,59,1685,20011

These data are compared to the cross sections or transmission calculated using the most recent resonance parameter set from the ENDF/B-VII library. SAMMY [5] was used to calculate the neutron capture cross section and transmission, including all experimental effects. In most cases, resonances up to 600 keV were resolved with sufficient statistics.

SAMMY Option: "NORMALIZE AS CROSS Section"

N.M.Larson+,ORNL/TM-9179/R8

Normalization and input options

Capture yield data may be normalized in a variety of ways; therefore, SAMMY allows the user to choose which normalization is to be taken. The normalization generally referred to as capture "yield" is the one shown in the equations in this section; this choice has the property that values are in the range from 0 to 1. Another commonly used normalization requires dividing by thickness *n*; in this case, the value approaches the capture cross section in the limit of zero thickness. Finally, the data may be normalized as $\left(1-e^{-n\sigma_{tot}}\right)\sigma_{tot}$, that is, by multiplying the yield by the total cross section. To use these options, the appropriate phrase must be included in the alphanumeric section of the INPut file:

```
NORMALIZE AS CROSS Section rather than yield
NORMALIZE AS YIELD Rather than cross section
NORMALIZE AS (1-E)SIgma
```

SAMMY accepts the yield divided by the areal density (thickness).
This quantity is in barn, but still different from the cross section
(even though we specify it "CROSS S" in SAMMY input").

Is ,SIG,,RAW appropriate?

- Reaction yields divided by the sample areal density Y_x/n are for EXFOR compilation. Some R-matrix analysis code (e.g., SAMMY) accept this quantity as a variation of reaction yield normalization.

- The name of this quantity depends on the author (e.g., yield, yield per thickness, effective cross section, experimental cross section)

- This quantity is in barn, and we have used ,SIG,,RAW (raw cross section), namely cross section not corrected for known effects.

- Problems for us of ,SIG,,RAW
  1. The name “raw cross section” does not explain the definition of this quantity.
  2. “raw” sounds not very appropriate for some people.

Summary and Proposal

- Some experimentalists report reaction yields in barn.
- This quantity must be distinguished from the cross section (,SIG) because we can use this quantity for resonance analysis only after correction for sample effects.
- Introduce a new quantity code for "reaction yield divided by the areal sample density" to avoid a generic code ,SIG,,RAW.
- ,RYL,,DAD (reaction yield divided by the areal sample density) could be a candidate as an extension of the reaction yield (,RYL).