Bnat(n,tot) as an International Standard

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Improving the B10 standard

The final accuracy of the evaluations relies on the quality of the experimental datasets being used. But the quality of the experimental datasets relies on the quality of the standards used as reference.

Big improvements have been done in the last decade, after the IAEA launched an international project for the "Maintenance of the Neutron Cross-Section Standards", adopting from ENDF/B the upgraded version of the GMAP code.

Historically, the principal international standards are a few constants at thermal point (the TNC table), besides the specific neutron xs of light elements (H, Li6 and B10) that have a special treatment in the R-matrix procedure, so then, the final uncertainties of the whole matrix relies on their accuracy.

New inputs are needed to increase the quality of this international effort and one of its more sensitive points is the standard value at thermal point of the B10(n,a) reaction, wich is standard from 25.3 meV to 1 MeV.

An Idealized standard

•A.D. Carlson, Metrologia 48(2012)S328

… Using as reference a neutron cross section standard it is not necessary to make a direct measurement of the neutron fluence. However, then it is necessary to measure the standards very accurately since any measurement relative to a standard is limited in accuracy to that of the standard.

An idealized standard should have the following characteristics:

- ***It should be possible to use the nuclide in elemental form, be chemically inert and not radioactive.***
- ***It should be easy to fabricate into various shapes.***
- ***It should be readily available; not expensive.***
- ***Monotopes are preferred.***
- ***It should have few (or no) other channels that could cause interference with the reaction of interest.***
- ***In the standards energy region, the cross section should be large with a minimal amount of structure.***

An Idealized standard

B10 + n reactions are very close to fulfil the idealized standard requirements.

Moreover:

– Their cross-section shape follows perfectly the 1/v law up to 5 eV,

So that, we can use its mathematical parametrisation, and its exact integral in the thermal energy region (20 to 60 meV) is then easily obtained.

– B10(n,a) is IAEA standard from 25.3 meV to 1 MeV. At thermal point the current standard value is 3844(31) b and so the integral in the thermal range (20 to 60 meV) is 127.1(1.0) b·eV.

These uncertainties in the Standards are dominated by USU (0.8%), what is relatively high if one considers that we are dealing with a primary standard.

In any case, the evaluation of the B10(n,a) thermal value is tightly tied to the U5(n,f) value in such a way that any improvement in the B10(n,a) accuracy will produce a decrease of the whole TNC's associated uncertainties.

The effect of n-elastic channels

B10(n,a) can be accurately deduced from Bnat(n,tot)

Natural Boron is composed of only two isotopes: B10(19.9%) and B11(80.1%)

B10+n at thermal and near-epithermal energies show only three channels: two are neutron capture, that are followed, one by an alpha emission and the other by an alpha plus a *gamma*; third is (n,el) of around 2.2(0.5) b.

B11(n,tot) cross section is dominated by the (n,el) of 5.1(2) b without any contribution to the alpha's channels.

Concerning the effect of impurities in the sample, their only effect at these energies should be in the (n,el) channel, what can be easily kept as negligible.

The correction by the different elastic channels should contribute with less than, let us say, 8(3) b, leading to an uncertainty component at thermal point below 0.1% when the (n,α) cross section is obtained from subtracting the (n,el) components from the (n,tot).

The uncertainty increases as the cross-section drops, being around 0.8% at 1 eV, but jeopardizing the experiment above few eV.

Bnat(n,tot) as close to an idealized standard

The B10(n,a) thermal value in the Standards is 3844(54) b

When using natural Boron as measuring sample for the (n, a) reaction, its cross-section value at thermal point is directly related with the B10 one, by just the isotopic ratio, i.e., 0.199.

There are in EXFOR four experiments giving Bnat(n,tot) at thermal point, and their mean value is 762.6(2.0) b, which give us a corresponding value for B10(n,a) of 3832(10) b, in good agreement with the Standard value.

In consequence, Bnat(n,tot) in the thermal region is still very close to the definition of an "idealized standard" and so a transmission experiment should provide an absolute measurement that can be reproduced in several facilities all around the world.

Performing transmission experiments with few samples and doing the analysis integrating on wide energy intervals will reduce both statistical and eventual systematic errors.

Adopting Bnat(n,tot) as an absolute reference

Therefore, I'm proposing to improve the Bnat(n,tot) evaluation, and adop it in the thermal region as reference:

It is very close to the Carlson's definition of an "idealized standard" and such a transmission measurement can be done in several facilities all around the world.

Its xs gives high values in the thermal range and its shape is without deviation from the 1/v law up to around 5 eV.

All in all, the correction by the different elastic channels in a (n,tot) measurement should contribute with less than 7(3) b leading to an uncertainty component at thermal point below 0.08% when deducing the (n,a) = (n,tot) – (n,el).

Boron XS shape at low energies

Bnat(n,tot) xs shape follows perfectly (within 0.1%) the 1/v law up to 5 eV, thus fitting to a straight-line in log-log scale (eV,b).

In general, in the thermal range, the XS should be taken in its mathematical form, with two and only two parameters:

$$\sigma(En) = \sigma_0 \cdot (En / 0.0253)^b$$

whose exact integral for any integration limits (E2>E1) is:

$$I_{(E2\text{-}E1)} = \sigma_0 \cdot (E2^{(b+1)} - E1^{(b+1)}) / (0.0253^b \cdot (b+1)$$

and in the particular case of the thermal range with b= -0.5 it is easily obtained:

$$I_1 = \sigma_0 \cdot (0.06^{(0.5)} - 0.02^{(0.5)}) / (0.0253^{-0.5} \cdot (0.5))$$

(Note: only lighter nuclei show an exact 1/v behavior (<01%))

These properties allow us **to obtain the thermal XS, σ_0, directly from integral values well above the thermal point**, as long as the 1/v approach is valid. This integration method highly reduces the statistical errors.

Suggesting a Bnat(n,tot) transmission experiment

Schematic setup for measuring Bnat(n,tot) xs in the thermal and near-epithermal energy range.

A filter box able to easily manage several Bnat foils will allow to measure the beam attenuation for several thickness.

Both the samples and the beam monitor must cover the whole beam profile. The distance from the samples to the flux monitor should be big enough to minimize the number of scattered neutrons arriving to the beam flux monitor

Absolute measurement of Bnat(n,tot)

Let R(En) be the counting rate in the beam flux monitor without any sample in the filter box at a neutron energy En, and let R'(En) be the reduced one when a thin sample (of thickness x) is added.
Both R(En) and R'(En) counting rates depend on the neutron flux, Φ, as well as on the flux monitor efficiency, ε, including the geometrical acceptances.
The neutron flux is attenuated:

$$\Phi' = \Phi \exp[-\mu/x], \qquad \text{where} \qquad \mu = \sigma_{tot}\, \rho\, N_A / A$$

(ρ density, A mass number, N_A Avogadro's number, multiplied by 10^-28 to get σ_t in b).

Obviously, doing R'/R , Φ and ε cancel and we have:

$$R/R' = \exp[\mu/x]$$

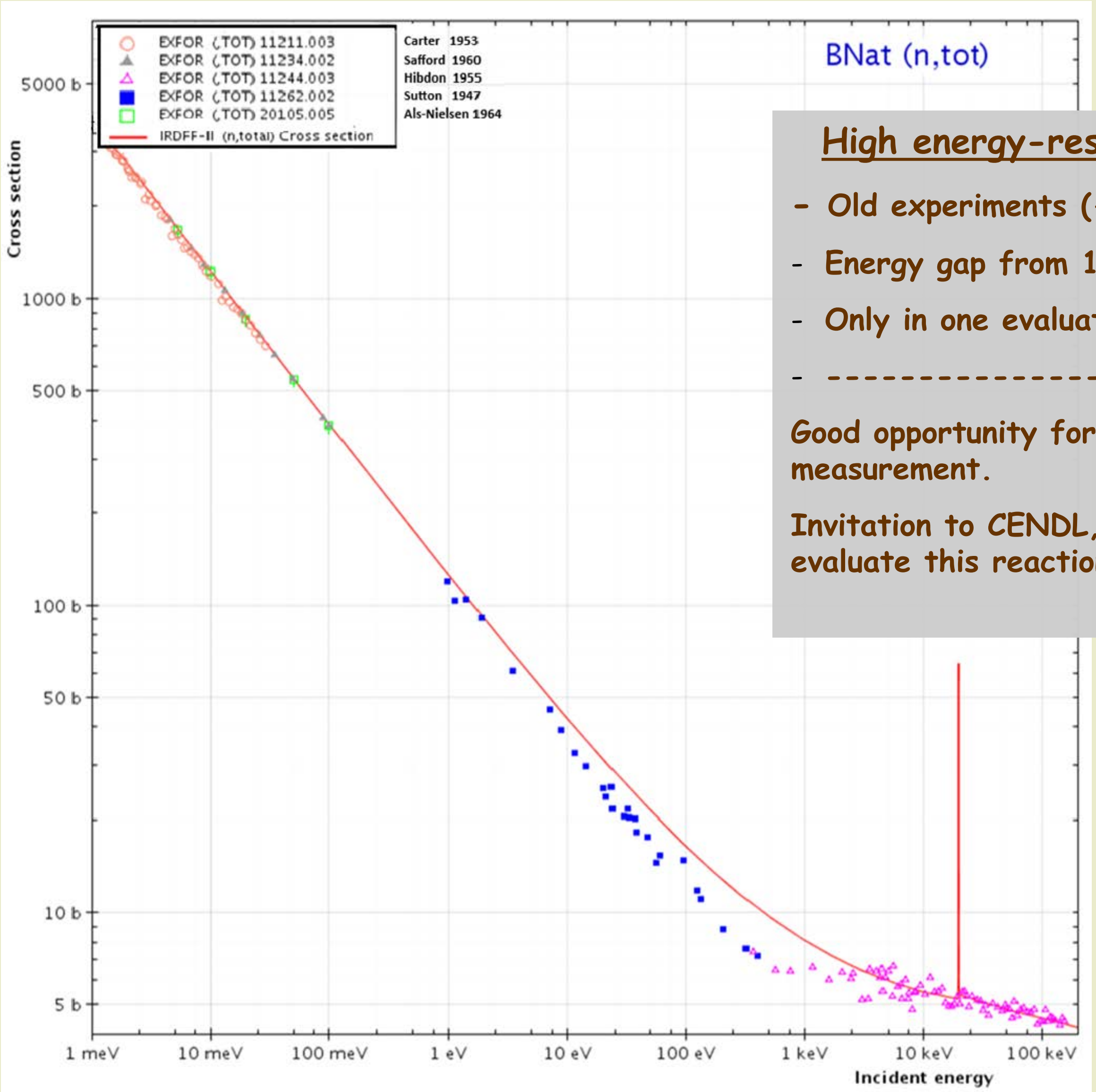
where x, ρ, A, N_A are constants and so, the ratio only depends on $\sigma_{tot}(E_n)$.

$$R(E_n)/R'(E_n) = \exp[C\, \sigma_{tot}(E_n)] \rightarrow \sigma_{tot}(E_n) = (1/C) \ln[R(E_n)/R'(E_n)]$$

Therefore, the cross-section uncertainty is dominated by both the sample parameters and the En calibration.

- This Bnat(n,tot) xs is an absolute measurement that eventually can reach uncertainties around 0.1%.

EXFOR Bnat (n,tot)



High energy-resolution datafiles from EXFOR

- Old experiments (<1964)
- Energy gap from 100 meV to 1 eV
- Only in one evaluated library (IRDF), and not so good!
- -- -

Good opportunity for a high-resolution/low uncertainty measurement.

Invitation to CENDL, BROND and other major libraries to evaluate this reaction, fitting to the 1/v law (up to 5 eV).

Improving the B10(n,α) standard

The final goal can be to improve the standard value of B10(n,a) at thermal point, that currently in the NS18 is 3844.1(5.4) b.

A value obtained from (n,tot) – (n,el) should give a more precise knowledge of this standard.
The final accuracy is given by the lack of good experimental values of (n,el)

The only high-resolution experimental file in EXFOR (Prosdocimi 1967) reports a value of 3836(9) b. The analytical value assuming the 1/v behaviour give us a value of 3835.5 b.

Some evaluated libraries still show the former NS09 of 3842.4.

Conclusions

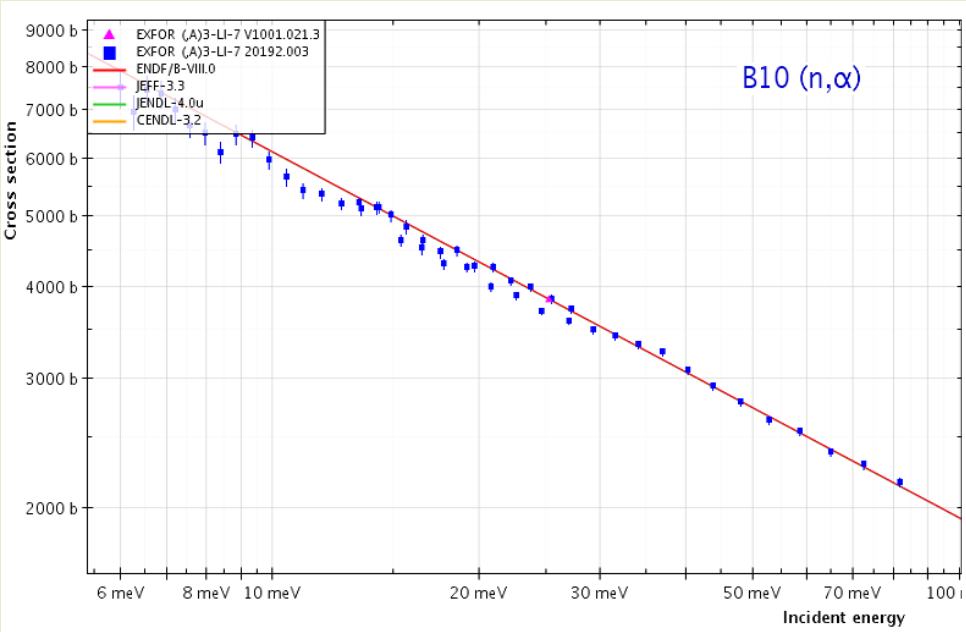
Being of interest improving the B10(n,a) standard:

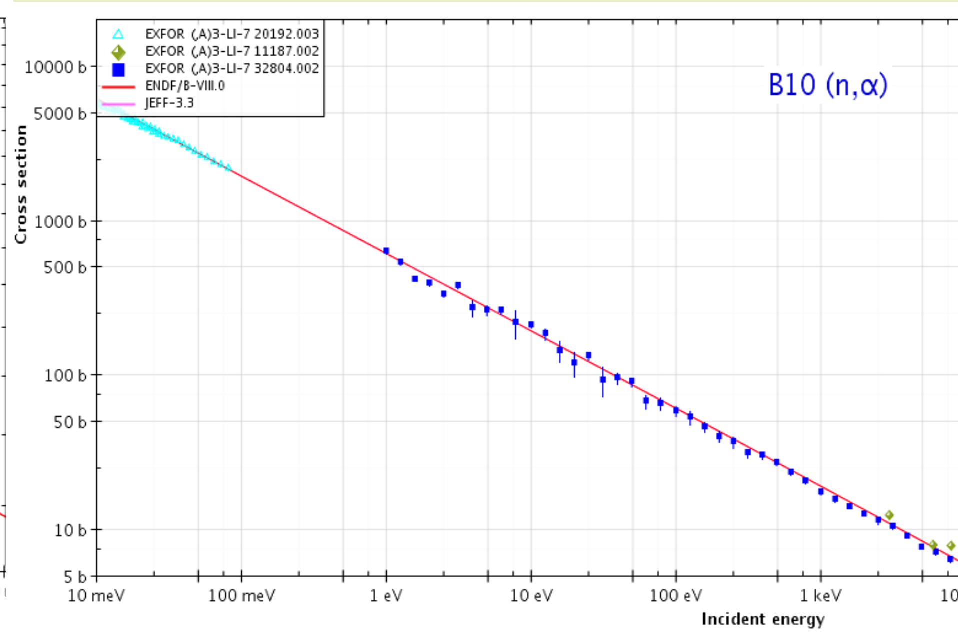
The most direct way to do it is by an absolute measurement of Bnat(n,tot), because the (n,el) reactions there involved can be managed, because they have much lower XS.

A Bnat(n,tot) transmission experiment using cumulative thin samples is not so expensive and can be reproduced at any facility all around the world with low uncertainty.

The method of extrapolating the thermal value from the integral value at higher energies, in the thermal and near-epithermal energy regions, should be precise enough, leading to an improvement in the knowledge of Bnat(n,tot) XS, and then to B10(n,α)

EXFOR B10(n,a)





Prosdocimi 1967

Haoyu Jiang (2019)