Feasibility Analysis of Unfolding Fast Neutron Spectrum by using (n, n' γ) reactions

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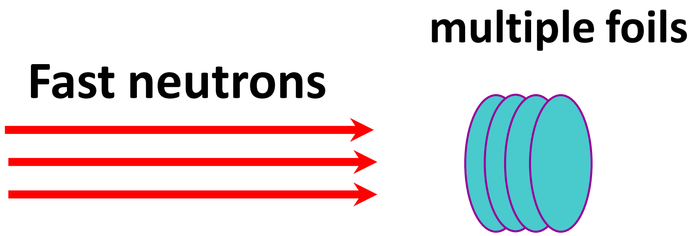
From NINT

Introduction

Multiple-foil activation method



Measure offline

Unfolding spectrum using SAND-Ⅱ, RDMM etc.

$^{23}Na(n,\gamma)^{24}Na$
$^{27}Al(n,\alpha)^{24}Na$
$^{27}Al(n,p)^{27}Mg$
$^{115}In(n,\gamma)^{116}In^{m}$
$^{37}Cl(n,\gamma)^{38}Cl$
$^{45}Sc(n,\gamma)^{46}Sc$
$^{46}Ti(n,p)^{46}Sc$
$^{47}Ti(n,p)^{47}Sc$
$^{48}Ti(n,p)^{48}Sc$
$^{64}Zn(n,p)^{64}Cu$
$^{63}Cu(n,\gamma)^{64}Cu$
$^{59}Co(n,\gamma)^{60}Co$
$^{58}Ni(n,p)^{58}Co$
$^{24}Mg(n,p)^{24}Na$
$^{55}Mn(n,\gamma)^{56}Mn$
$^{54}Fe(n,p)^{54}Mn$
$^{56}Fe(n,p)^{56}Mn$
$^{197}Au(n,\gamma)^{198}Au$
$^{98}Mo(n,\gamma)^{99}Mo$
$^{176}Lu(n,\gamma)^{177}Lu$
$^{164}Dy(n,\gamma)^{165}Dy$

Up to now, no more than 25 reaction channels can be used to unfolding the spectrum.

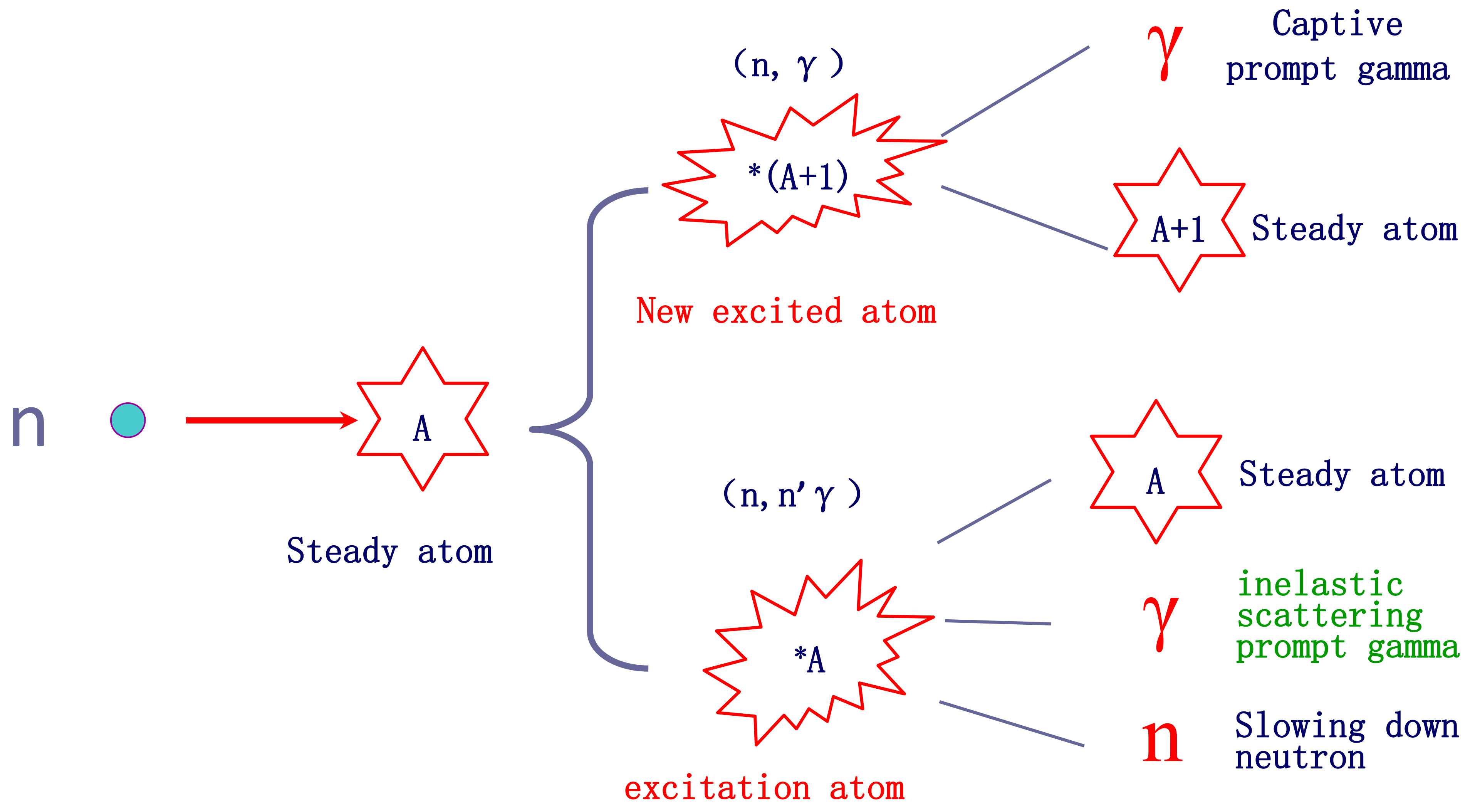
Furthermore, not all reaction channels can be used in one experiment because of the experiment conditions, such as the limitation of half-life, cross section etc.

The question:

How can we get more reaction channels?

Neutron inelastic scattering gamma

(n, n'γ)



Neutron inelastic scattering gamma

(n, n'γ)

(n, n' γ)

- (n, n'1)
- (n, n'2)
- (n, n'3)
- (n, n'4)
- ⋮
- (n, n'm)

Comparing with the multiple-foil activation method, each (n,n'm) reaction channel can be considered as a nuclide.

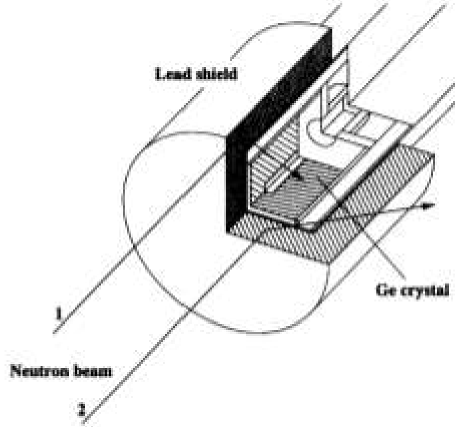
So, theoretically, we can easily have a large number of reaction channels which can be used to unfold the fast neutron spectrum.

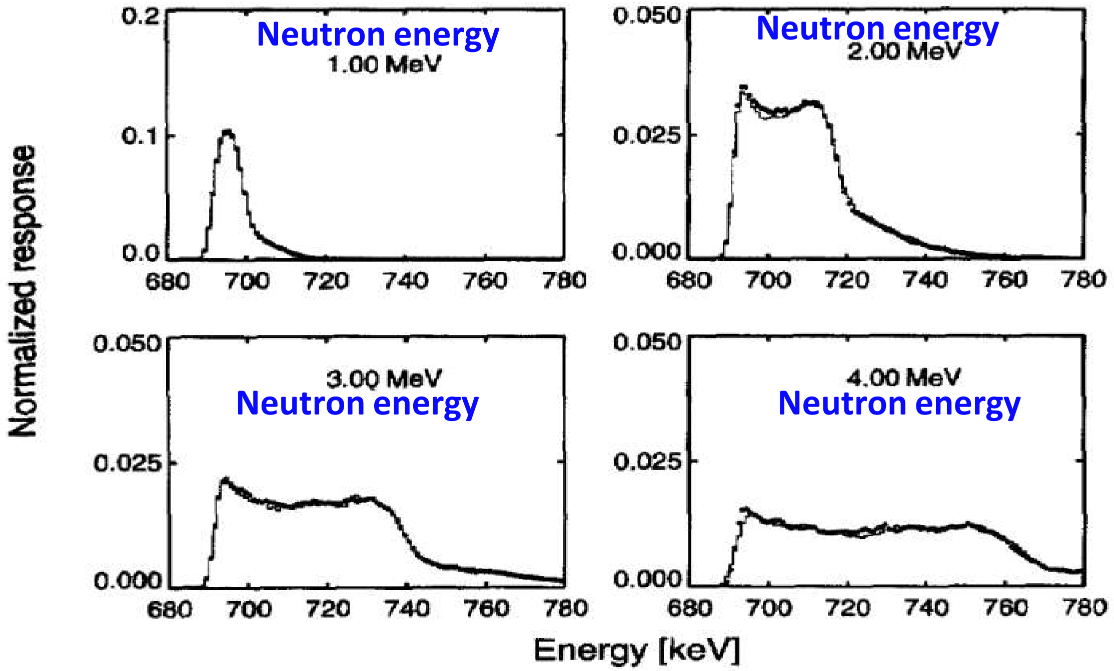
In 1991, H. Ejiri et al. firstly proposed the idea that the (n,n'm) reaction gammas could be used to determine the incident neutron energy.

Neutron inelastic scattering gamma

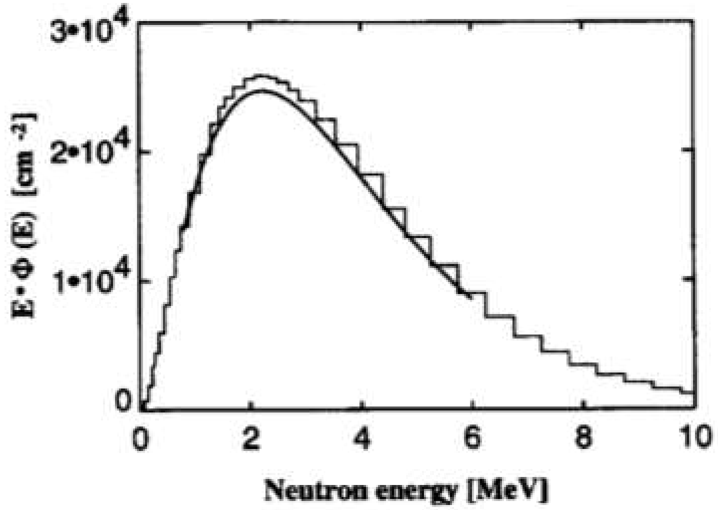
（n, n'γ）

In 1997, G. Fehrenbacher et al. from Germany used the HPGe detector to directly measure the energy of (n,n'r) gamma and recoiling Ge ion. Because of the recoiling Ge ion, the 692KeV peak is broaden wider than before.





Gamma spectrum



the unfolded neutron spectrum of ^{252}Cf

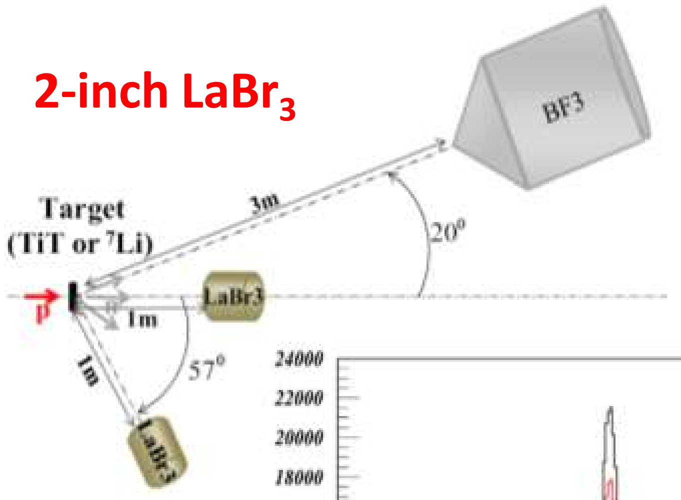
Neutron inelastic scattering gamma

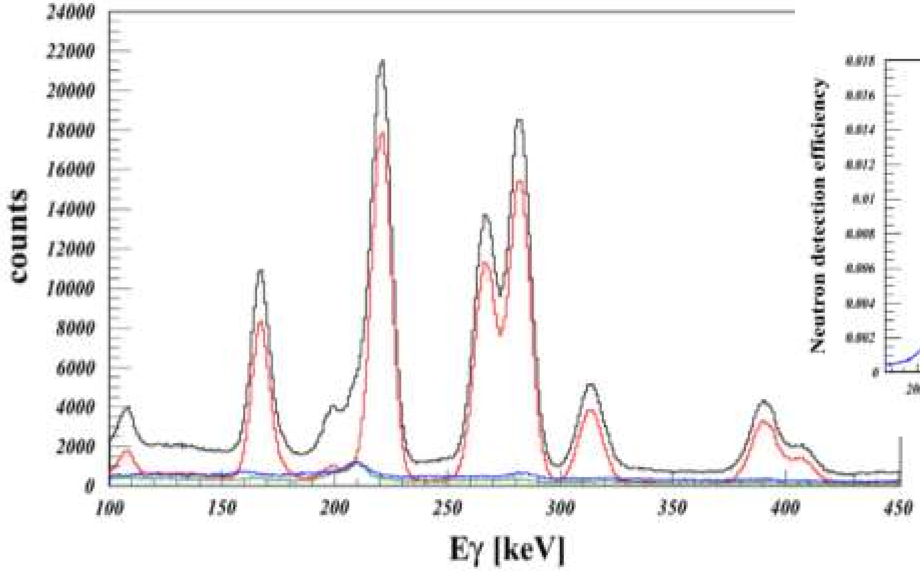
(n, n'γ)

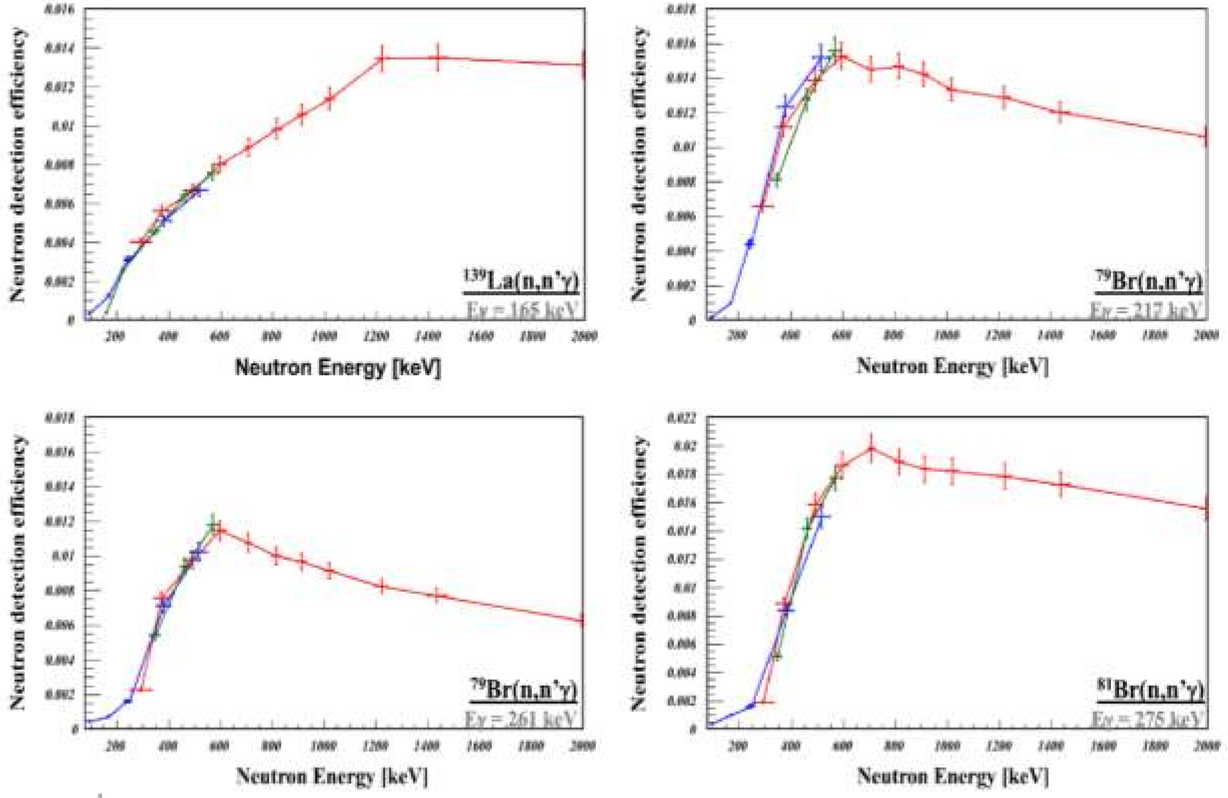
In 2014, A. Ebran et al. in CEA measured the neutron efficiencies relative to five γ-rays produced in (n, n'γ) of La and Br in LaBr3:Ce detector.

isotopes	^{139}La*	^{79}Br*	^{81}Br*	^{79}Br*	^{79}Br*
gamma(keV)	165	217	261	275	306

2-inch $LaBr_3$







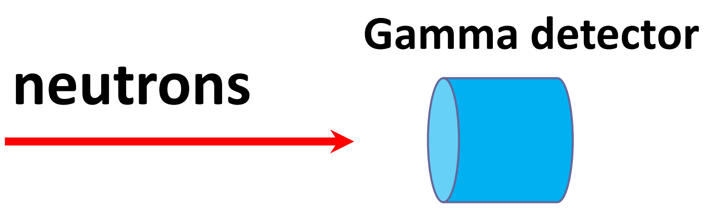
Neutron inelastic scattering gamma

（n, n'γ）

Shortcomings in above experiments:

- the detector directly reacts with neutrons. The gammas accompanied with neutrons are acting as the strong background. And this method can lead to detector damage.

- the number of isotopes in the detectors is too small to get enough (n, n'm) channels.



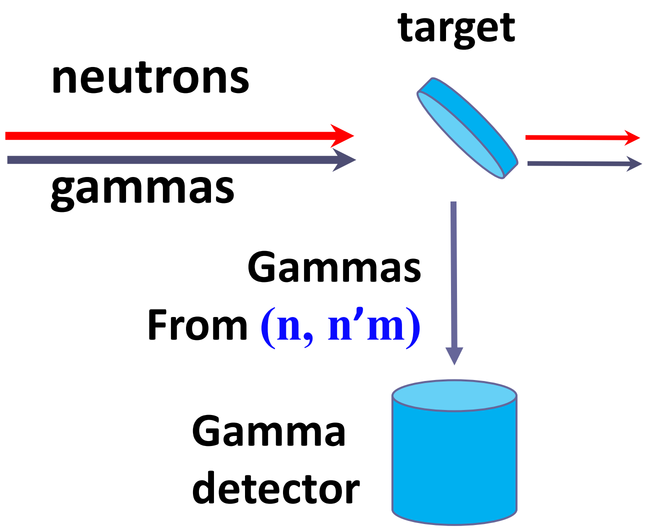
Pure matter, less isotopes

How to solve these problems?

Neutron inelastic scattering gamma

An alternative solution

(n, n’γ)



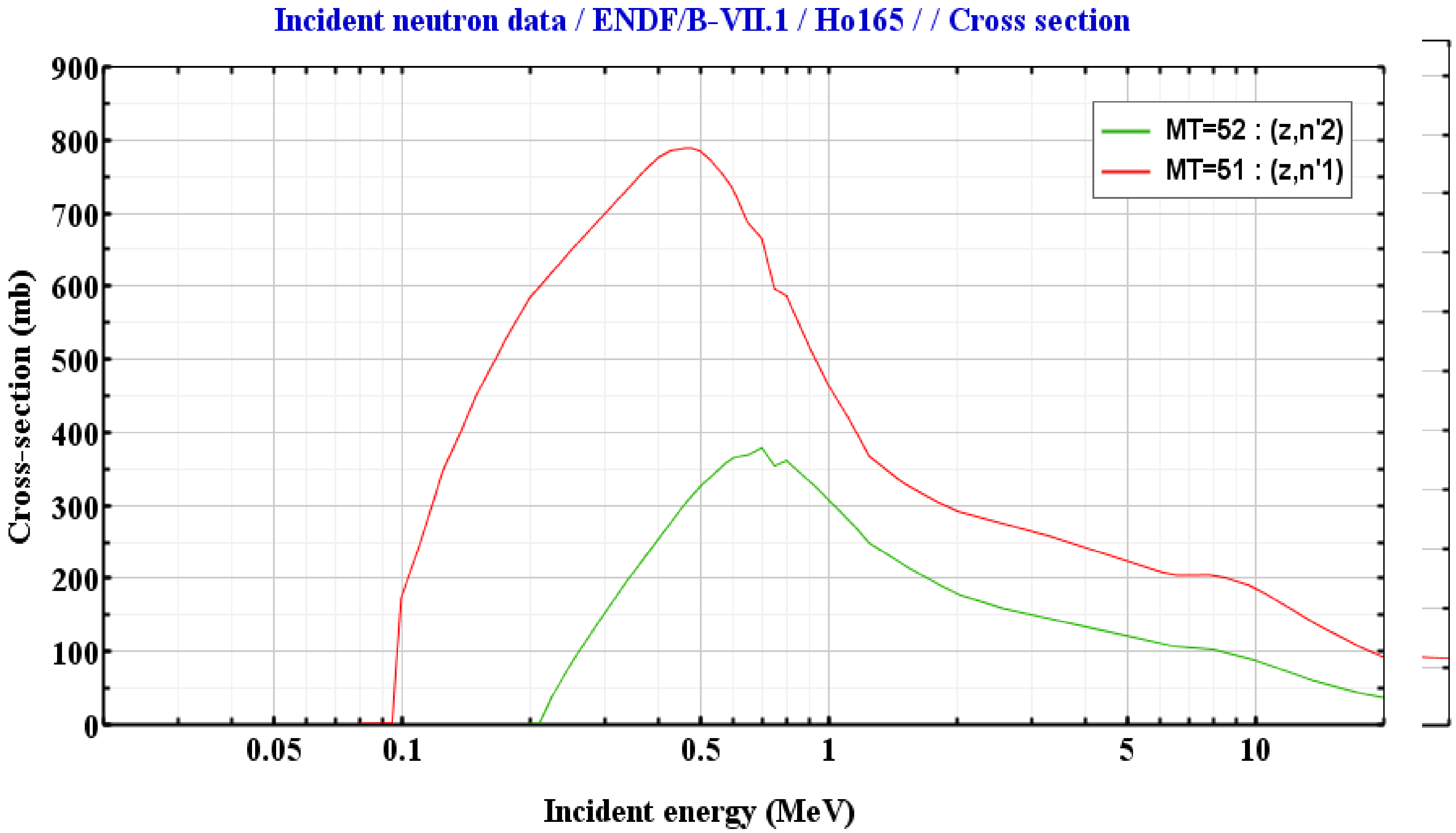
Right or obtuse angle
Significantly decrease the BK

Two target modes

- **Multi-nuclide-mode target**: Lots of elements must be needed and every element has one or more usable (n, n’m) channels.
- **Multi-γ-ray-mode target**: One element has several isotopes and every isotope has several usable (n, n’m) channels.

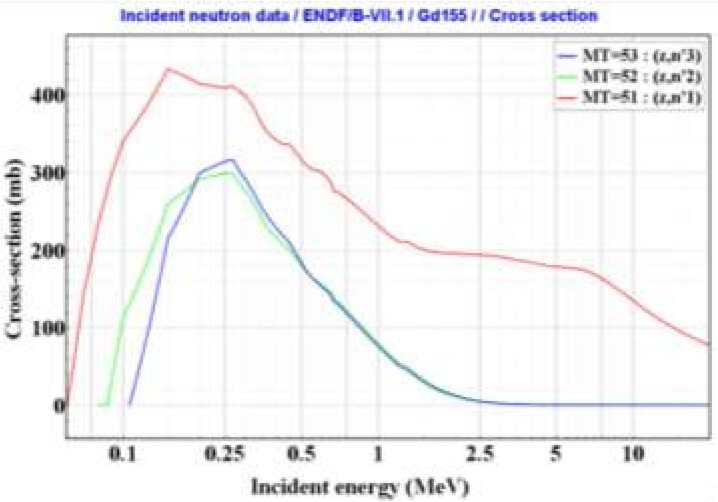
Multi-nuclide-mode target

To ensure the detecting sensitivity, the cross section of (n, n'm) must be up to 0.2 bar.

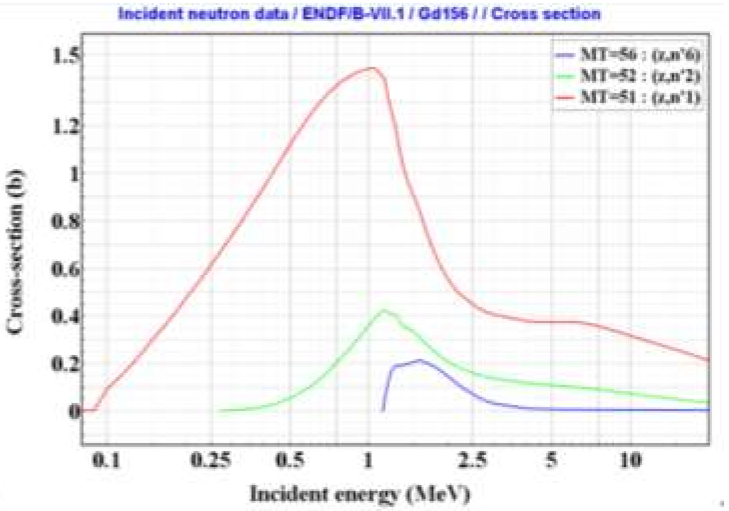


Mg、Br、Rb、Y、Nb、Rh、Sb、I、Pr、Ho

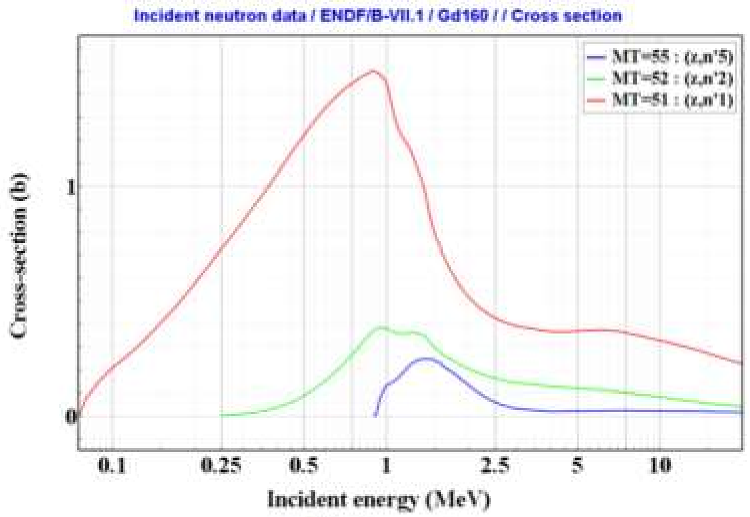
Multi-γ-ray-mode target



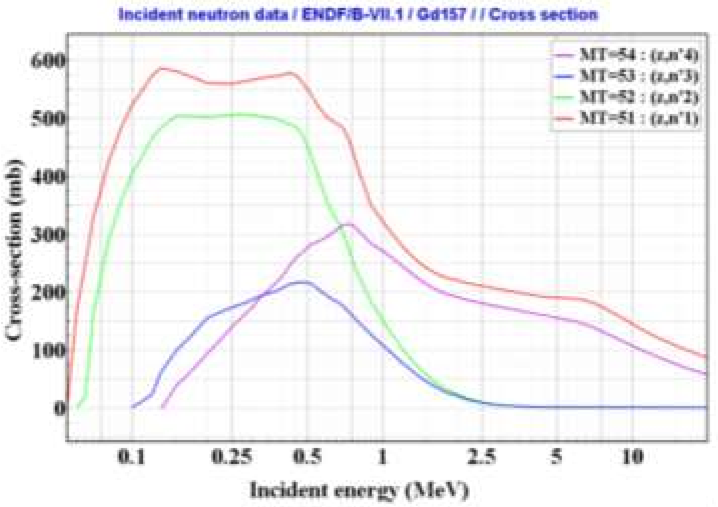
(a) ^{155}Gd(n, n'm)



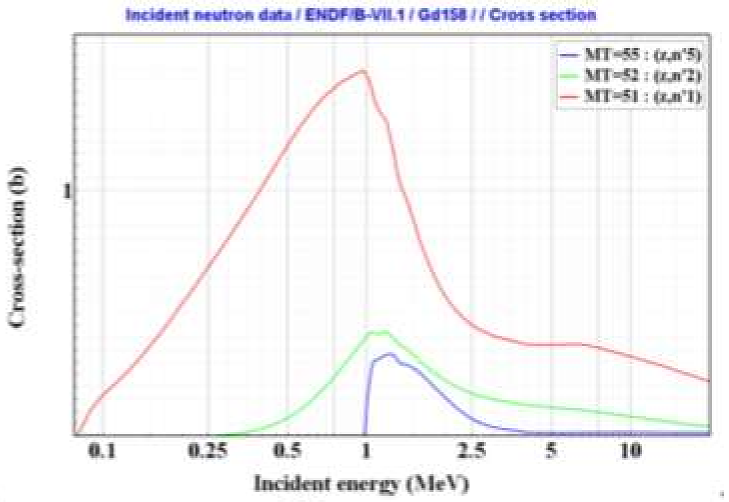
(b) ^{156}Gd(n, n'm)



(e) ^{160}Gd(n, n'm)



(c) ^{157}Gd(n, n'm)



(d) ^{158}Gd(n, n'm)

Five main isotopes of Gd

Considering the cross sections, there are at least fifteen (n, n′m) gammas can be used in Gd.

Sm, Nd, Pd, Ru etc. are the same element as Gd.

How to do?

Select the elements	Choose the proper elements meeting your experiment.
Buy the pure matter	Prepare the pure matter according to above selection.
Make the target	Choose proper pure matter and make a mixing target evenly
Calibrate the target	Measure the corresponding function vs. neutron energy
Use the target	Set the target to proper position relative to neutron source
Measure the gammas	Let neutrons react with the target and measure the (n, n'm) gammas
Unfolding neutron spectrum	Use the unfolding programs to get the spectrum of neutron source

Summary

- **Analyzed the shortcomings of Multiple-foil activation method in unfolding fast neutron spectrum.**
- **Proposed an alternative solution for better measurement of the (n, n'm) gammas**
- **Suggested two target modes**
- **Analyzed some typical usable (n, n'm) gammas and the elements**
- **Summarized the whole experiment procedure**

Thanks for your attention!