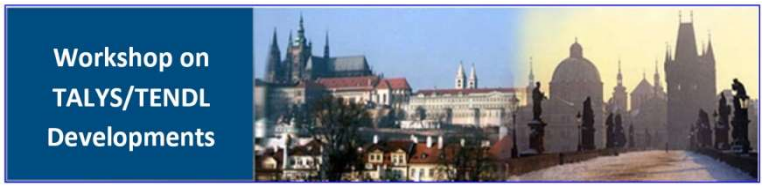


Center of Accelerators and Nuclear Analytical Methods - CANAM

Nuclear Physics Institute of the CAS
public research institution

THE BENCHMARK OF THE EAF-2010 NEUTRON CROSS-SECTIONS IN THE ENERGY RANGE 20-35 MEV

M. Majerle, M. Ansorge, P. Bém, J. Novák,
E. Šimečková, M. Štefánik

Nuclear Physics Institute of the CAS, Řež

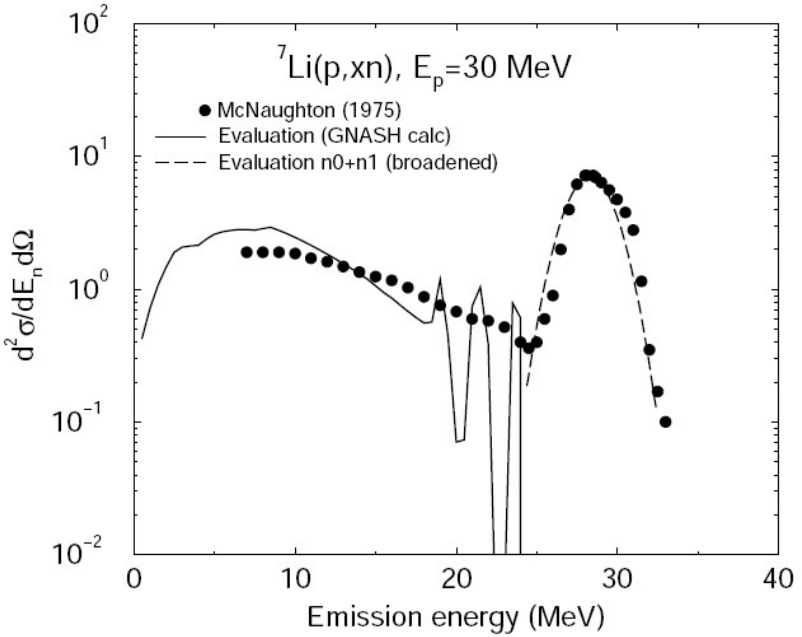
Outline

- F4E-2008-GRT-014 and TW7-TTMN-002B, (n,xn) on Au, Bi
- F4E-2009-GRT-056, (n,xn) on Nb, Co
- F4E-FPA-395 (2013-present), gas production – (n,cp) on steel components, Fe, Cr, Ta, W
- IRDFF v1.05 benchmarking (2016), (n,x) on Au, Bi, Co, Fe, Tm (decrease uncertainties)

- EAF-2010 for CS extraction, but TENDL-2015 was used several times during in the analysis, some problems are pointed out
- Activation method (irradiation in known neutron spectrum, HPGe measurements)
- Neutron source (p+Li)
- Neutron spectra (Li library needs update, next talk by J. Novák)
- Cross-section extraction
- Uncertainties
- Cross-section data

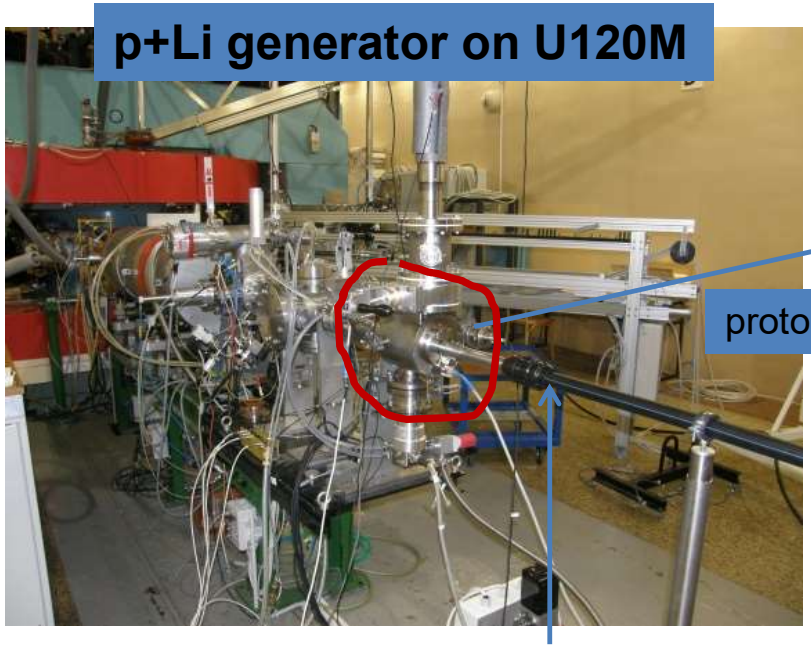
Neutron source

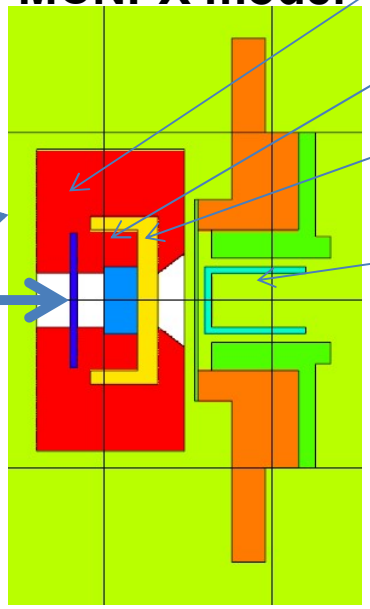
- Above 20 MeV quasi-monoenergetic spectrum
- Reaction p+Li
  - Direct component – peak neutrons (Q=1.6 MeV), main peak (ground and first excited ^{7}Be) and smaller peaks
  - Compound component (isotropic emission at lower energies).



Mashnik evaluation, https://arxiv.org/abs/nucl-th/0011066v1

Neutron source at NPI, p+Li (2mm)



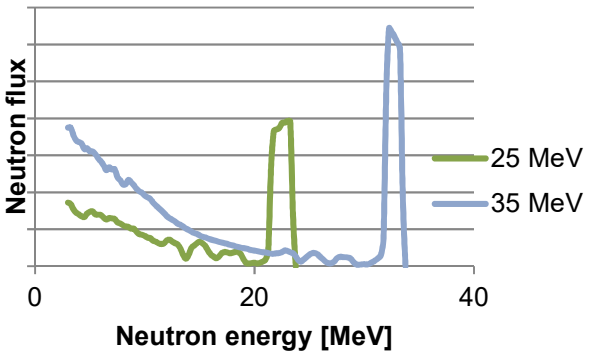


2 mm ^{7}Li target

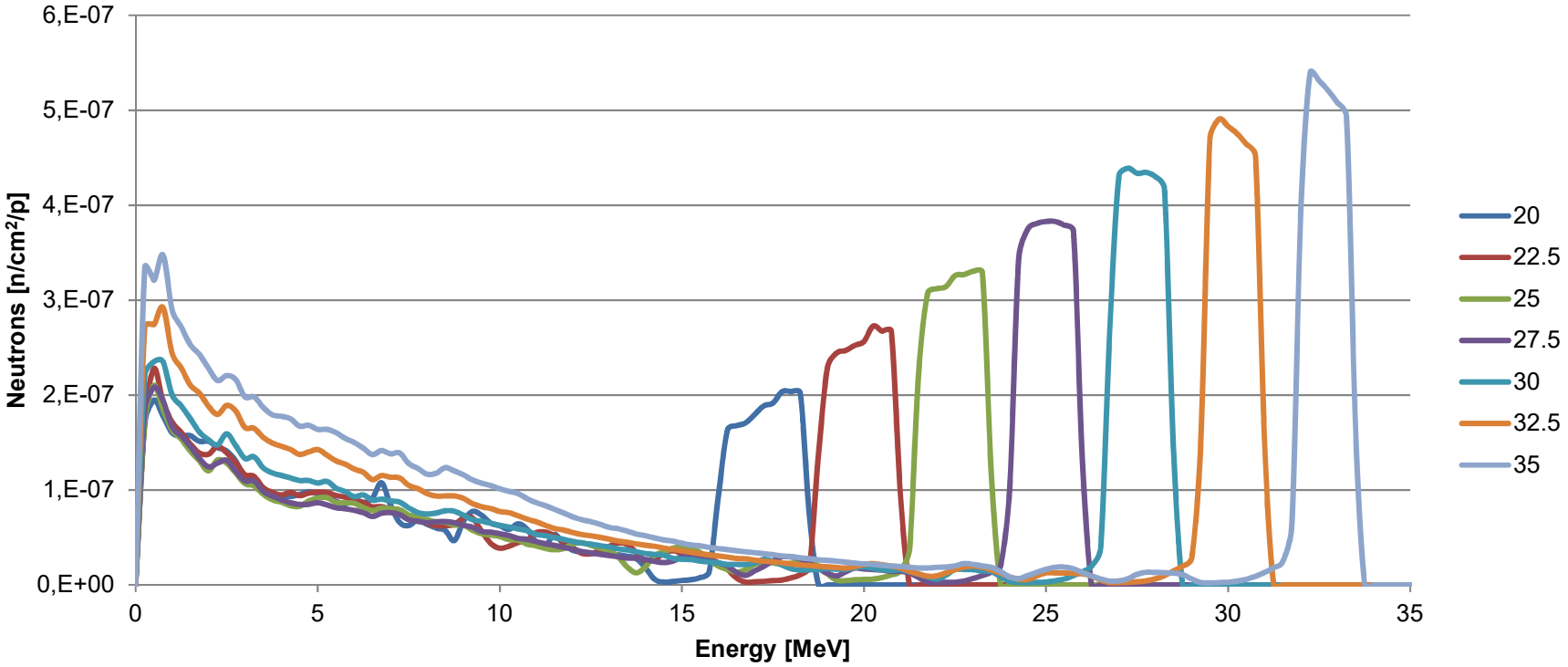
Carbon beam stopper

Cooling – ethanol

Transport container with irradiated sample

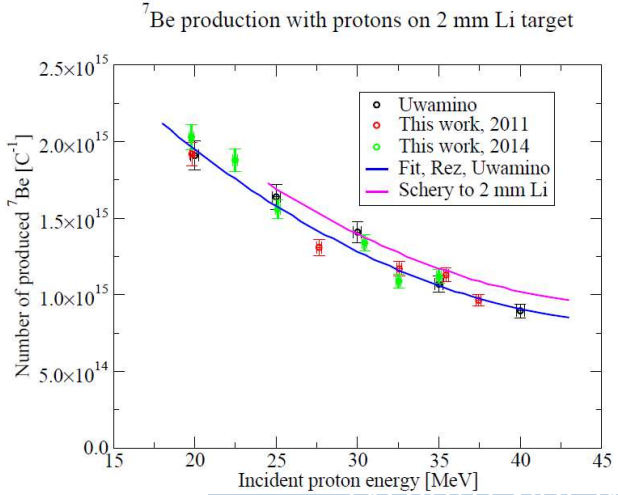


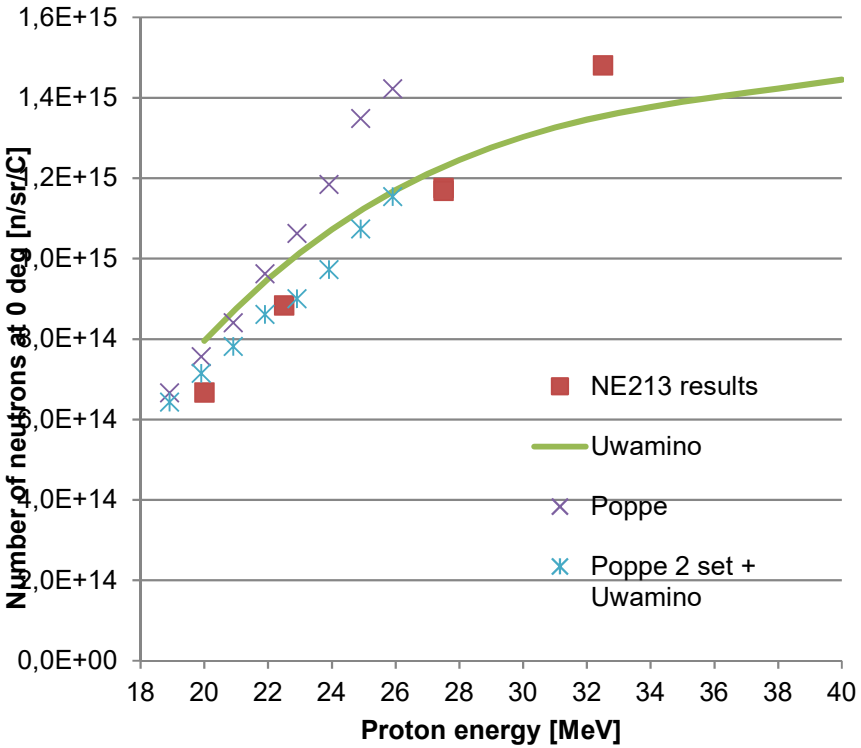
Neutron spectra



Number of peak neutrons

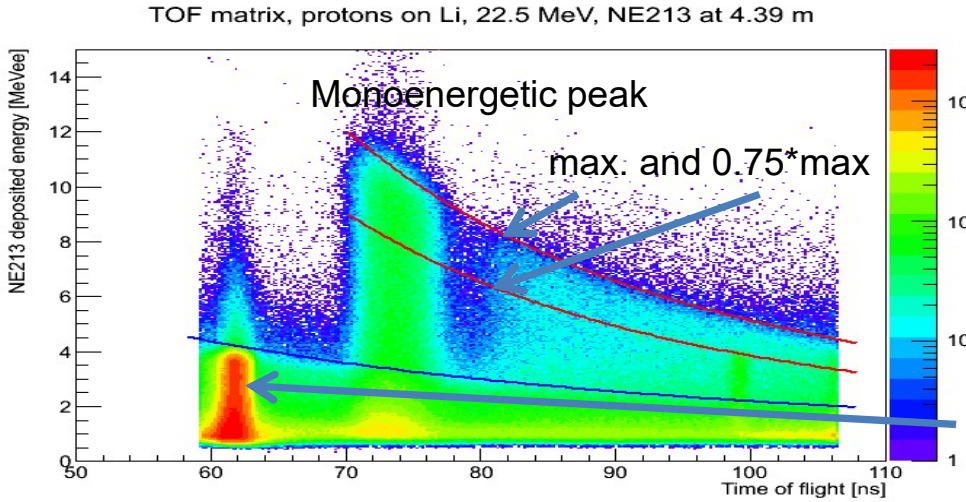
- Number of produced ^{7}Be (measured by HPGe in the Li after irradiation, 2%) = number of monoenergetic neutrons in 4π
- Forward directed neutrons - calculation
- Experimental measurement by NE213



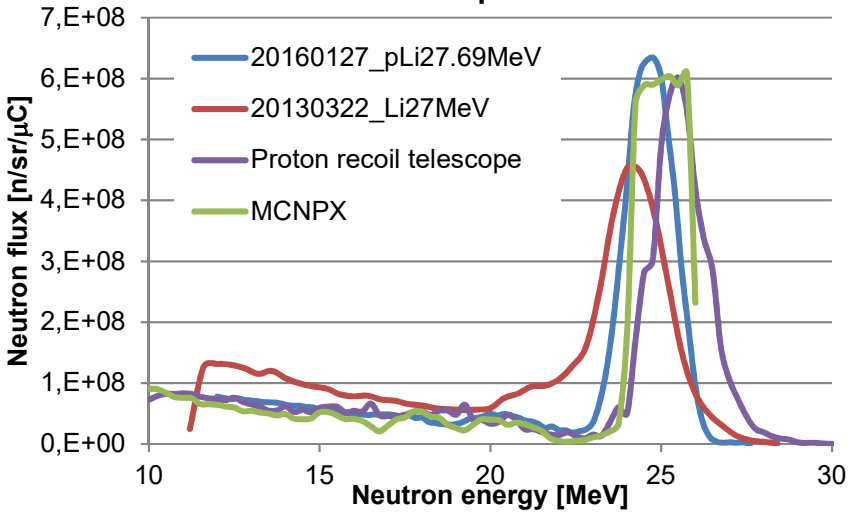


Shape of the neutron spectra

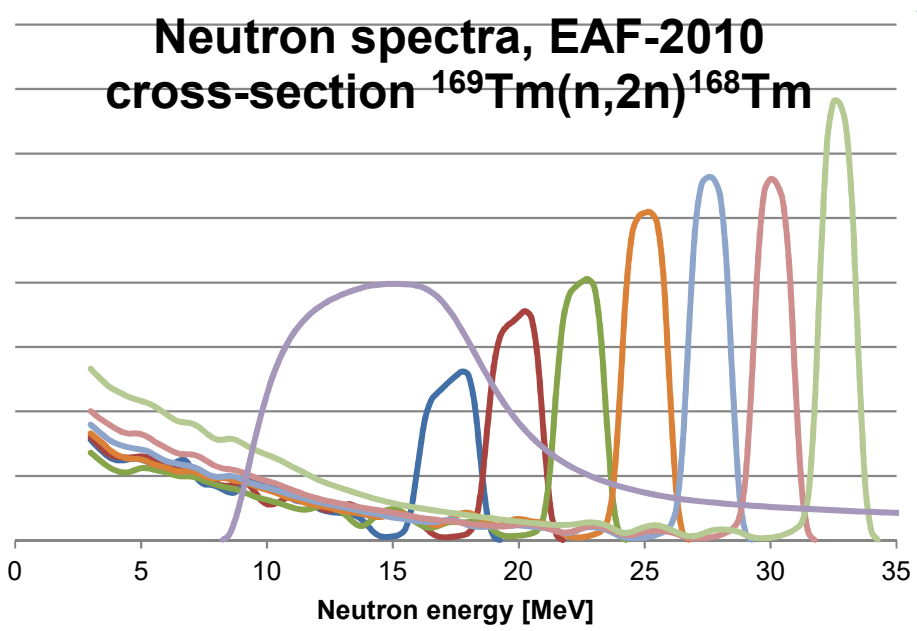
- TOF measurement, normalized to (n,p) on ^{1}H
- Cyclotron RF period: 40-50 ns, frame overlap (ca. 15MeV)
- TOF measured with NE213 2”x2” at 4-5m, CAEN digitizer



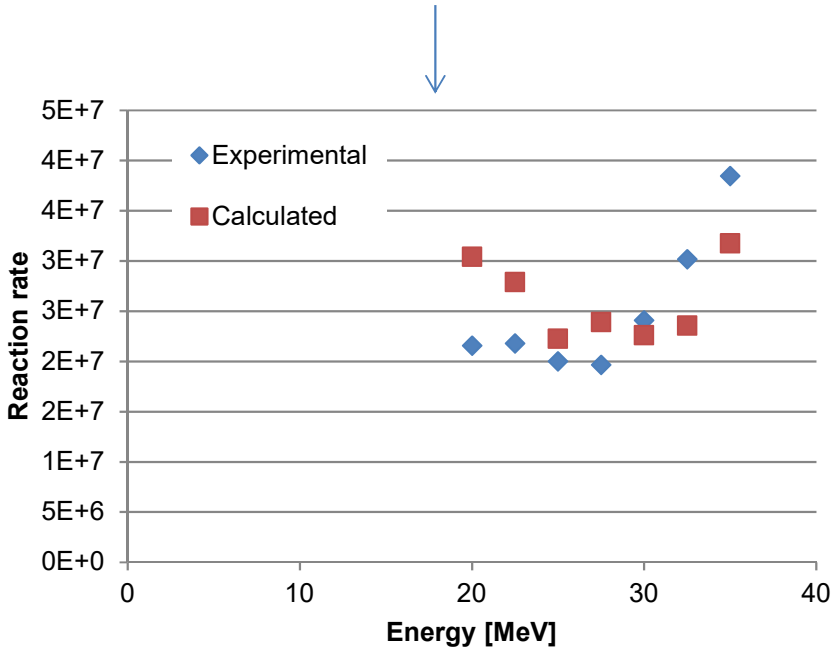
Comparison of experimental and simulated neutron spectra



Spectra+input XS=reaction rate

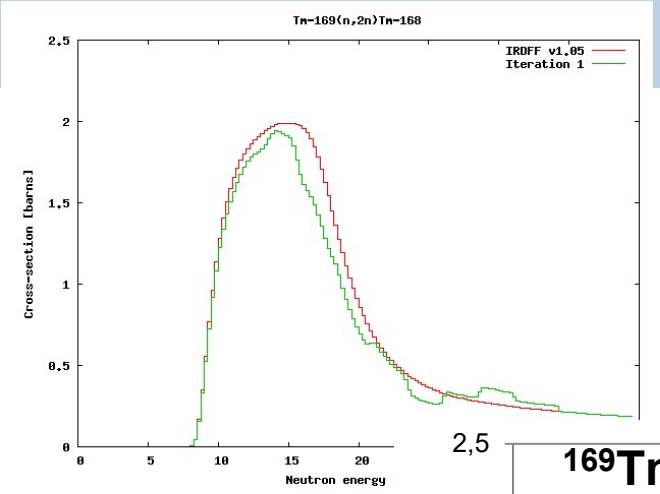


Folding spectra with cross-section

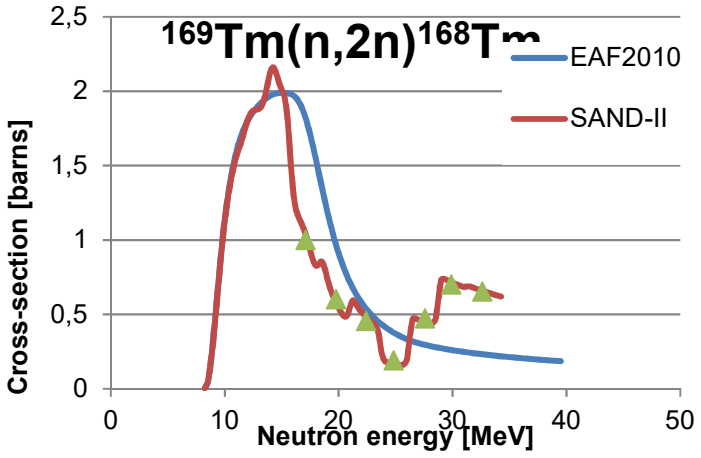


Unfolding gives XS

- SAND approach
  - Iterative
  - Cross-section varied until calculated and experimental RR do not agree
  - **Uncertainties** evaluated by **sensitivity analysis**
- STAYSL approach
  - Least square fitting
  - Input covariances, etc…
- Similar results



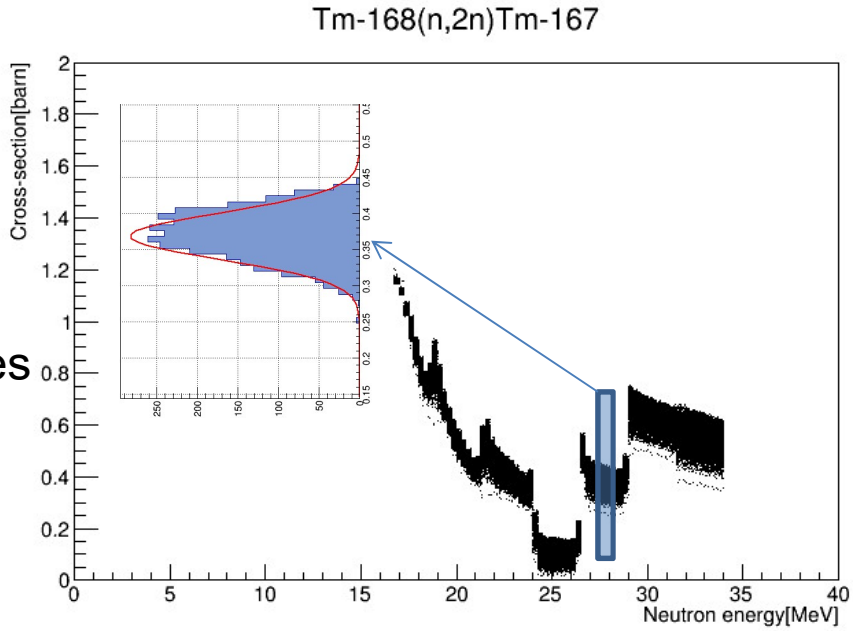
SAND iterative approach

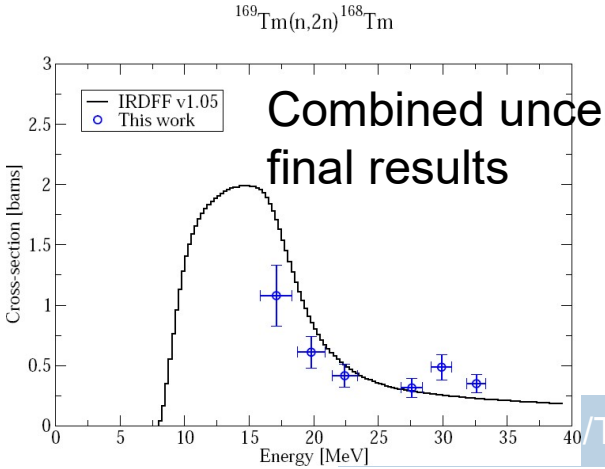


Evaluating uncertainties

- Sensitivity analysis:
  - Extraction with varied input
    - Peak neutrons (5%)
    - Neutron spectrum (<15%)
    - CS input function (negligible)
    - Accuracy, systematic uncertainties

Sensitivity analysis: variation of LE neutron tail

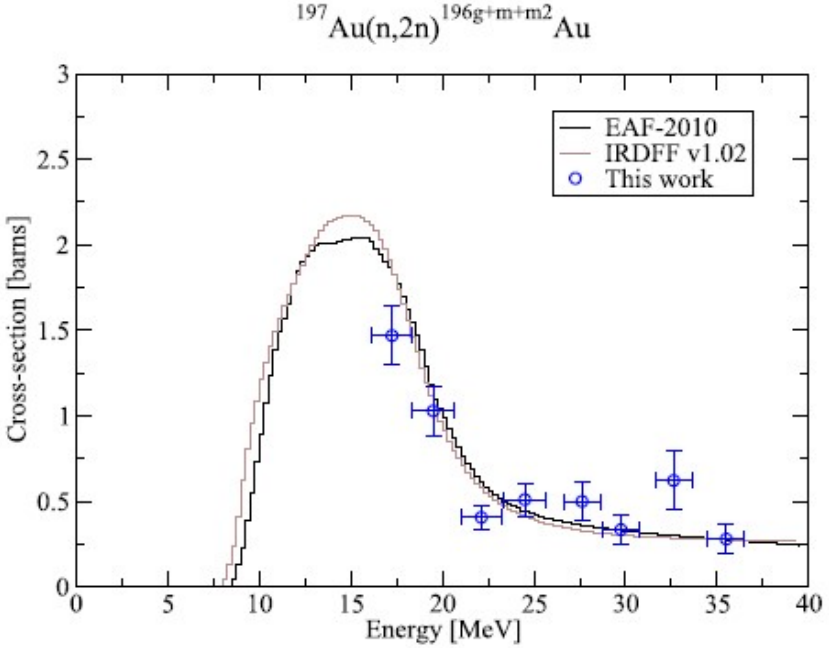


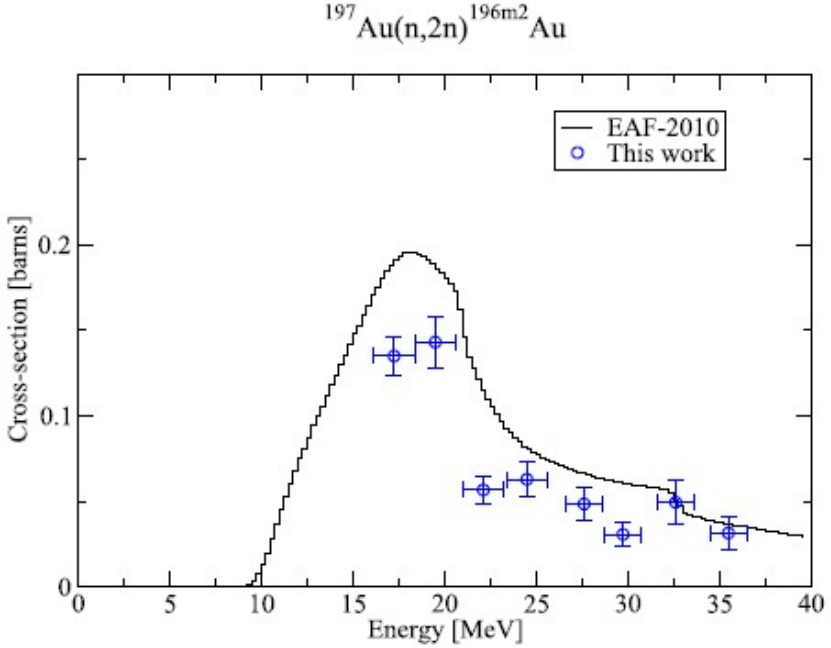


Combined uncertainties final results

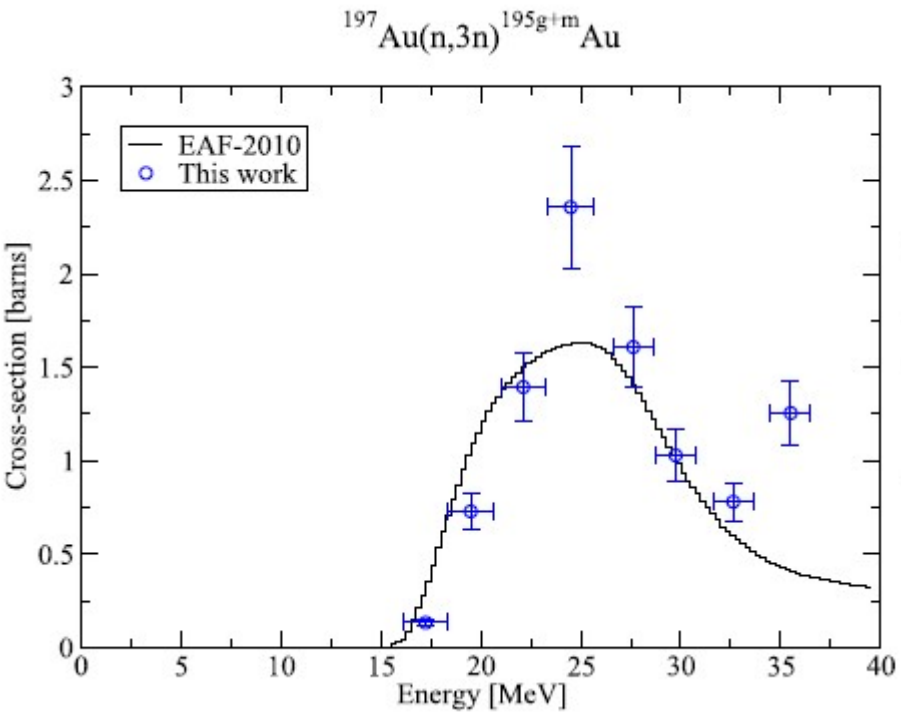
(n,xn) on Au, Bi, Co, Nb

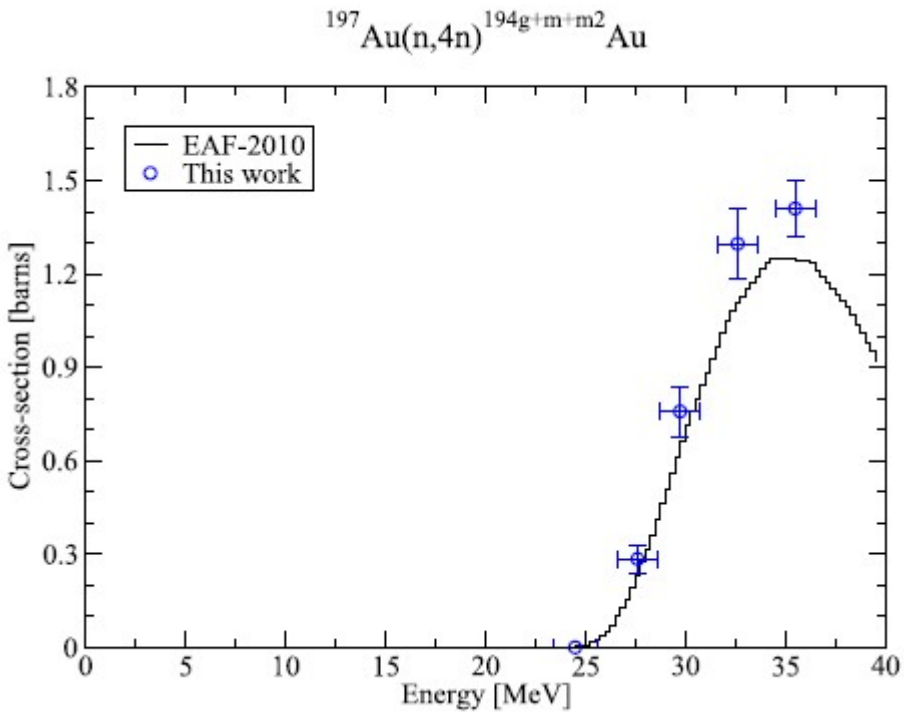
- Neutron monitoring reactions, intensive gamma lines, $t_{1/2}$~hours,days
- Measurements 2008-2013, F4E-GRT-014/056
- Nucl Phys A 953 (2016) 139-157, INDC(CZR)-0002



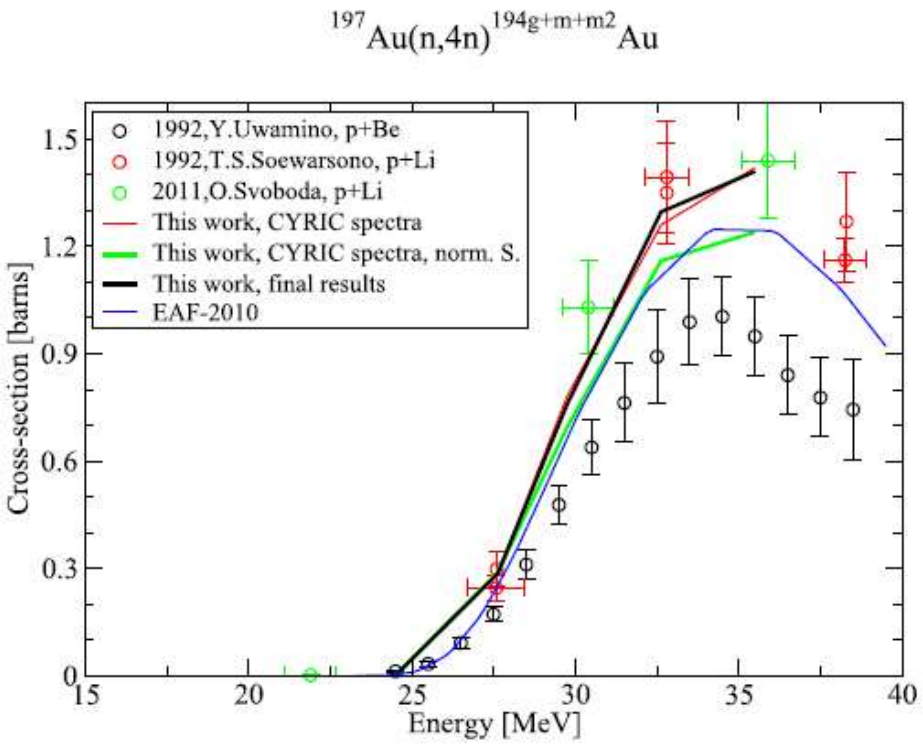


(n,xn) on Au, Bi, Co, Nb

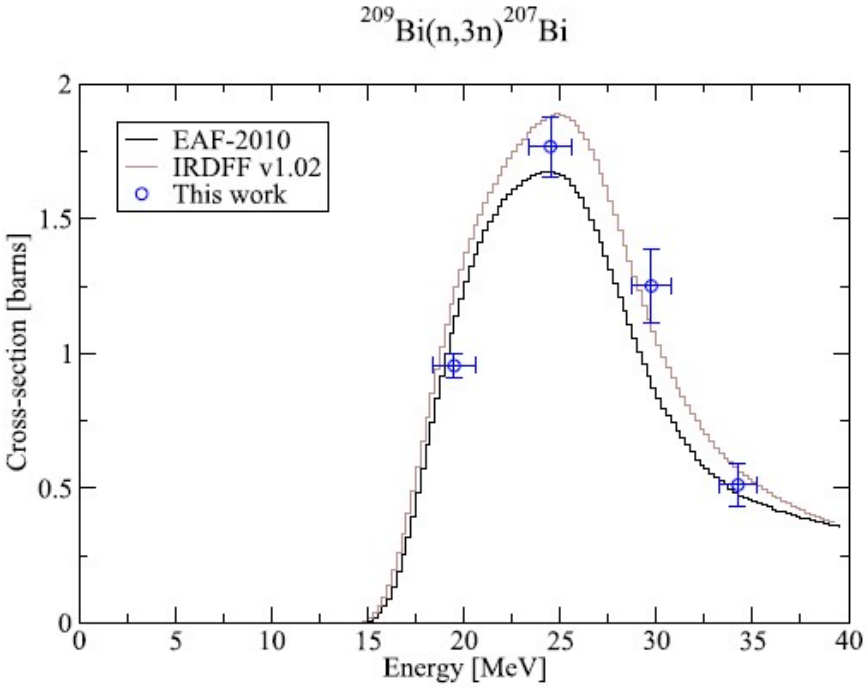


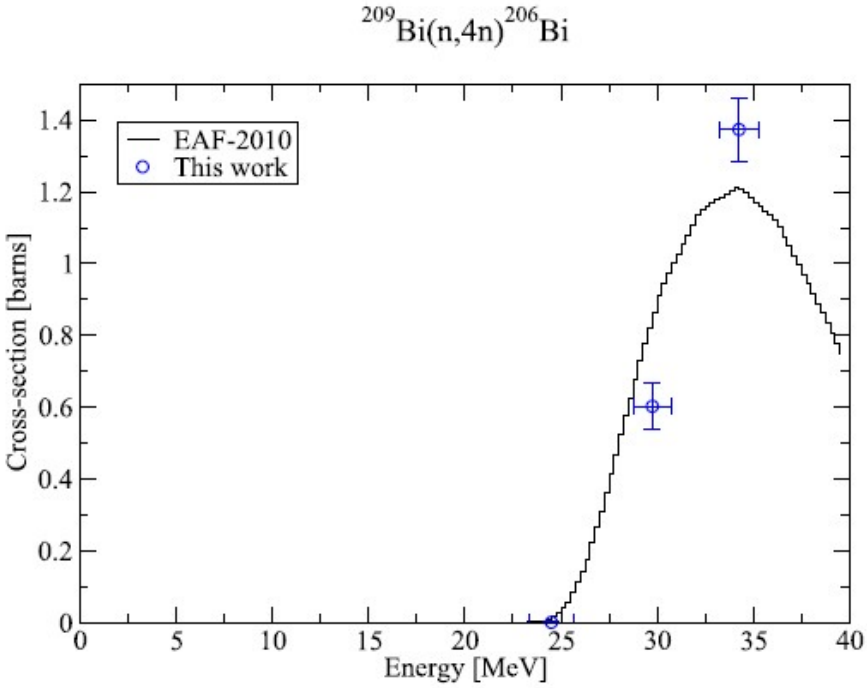


(n,4n) on ^{197}Au

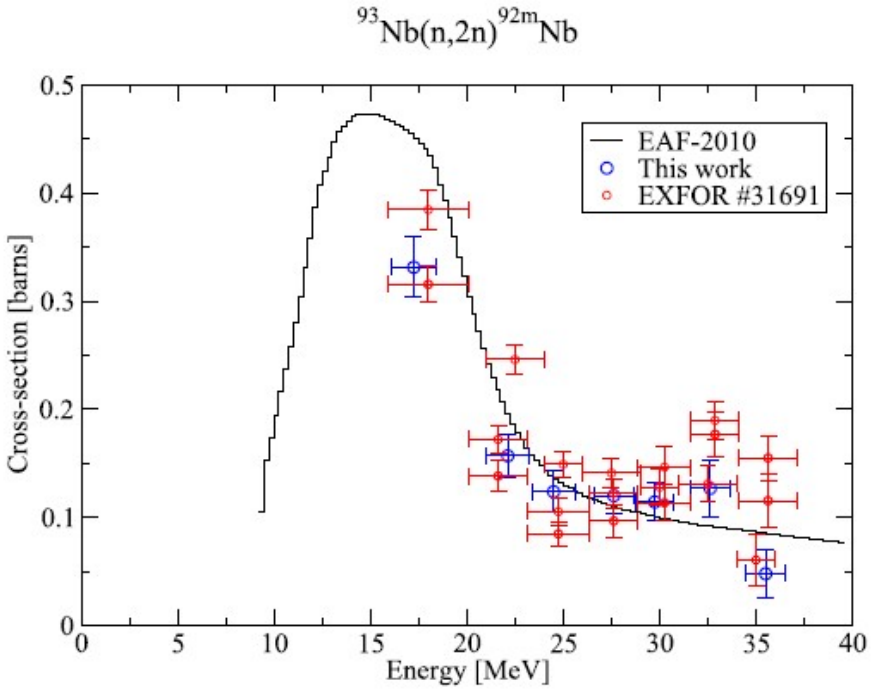

197Au(n,4n)194g+m+m2Au
1992,Y.Uwamino, p+Be
1992,T.S.Soewarsono, p+Li
2011,O.Svoboda, p+Li
This work, CYRIC spectra
This work, CYRIC spectra, norm. S.
This work, final results
EAF-2010
Cross-section [barns]
Energy [MeV]
0
0.3
0.6
0.9
1.2
1.5
15
20
25
30
35
40

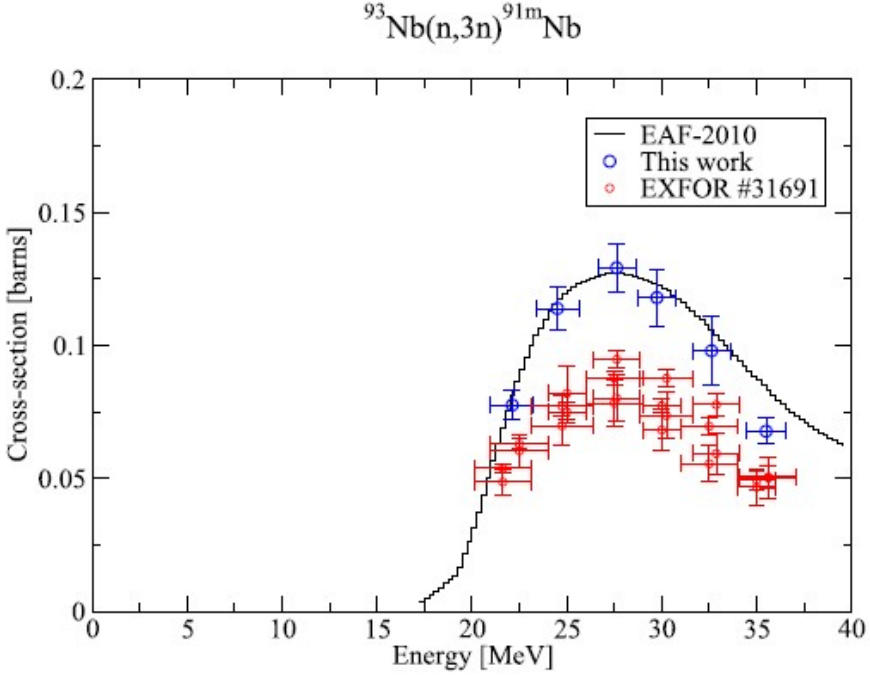
(n,xn) on Au, Bi, Co, Nb



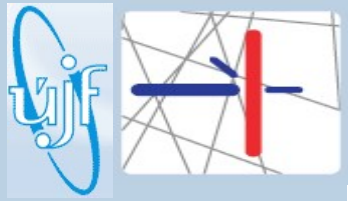


(n,3n) on ^{93}Nb


93Nb(n,2n)92mNb
EAF-2010
This work
EXFOR #31691
Cross-section [barns]
Energy [MeV]

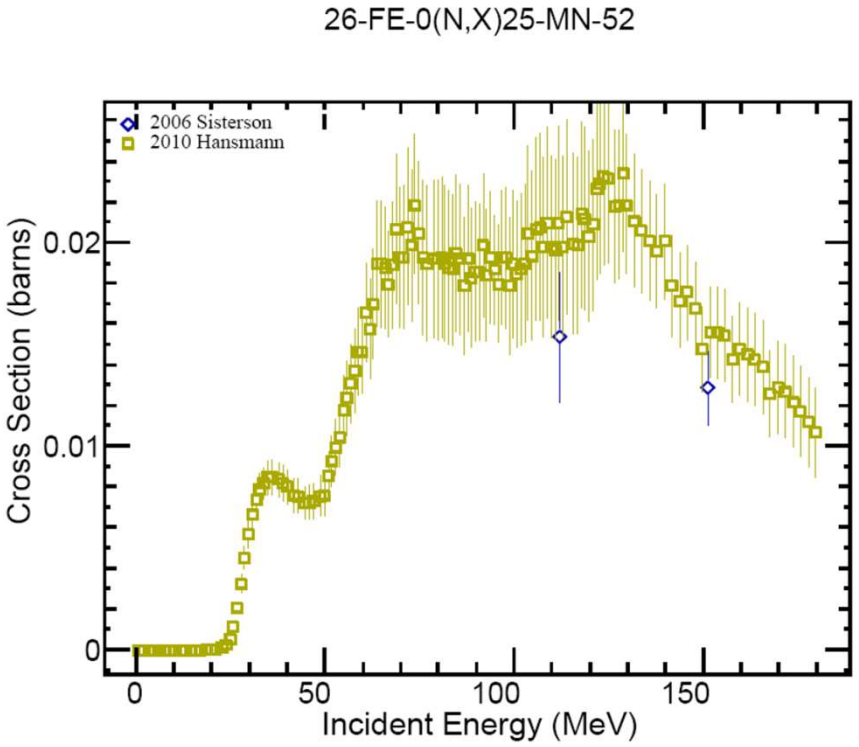

93Nb(n,3n)91mNb
EAF-2010
This work
EXFOR #31691
Cross-section [barns]
Energy [MeV]

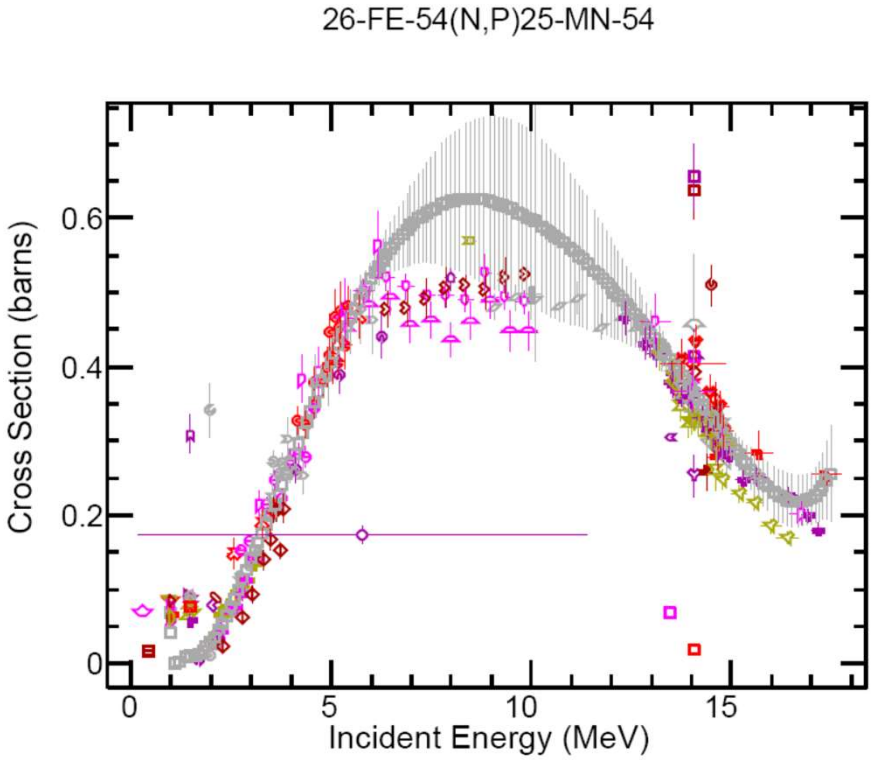
Gas production in ITER steel



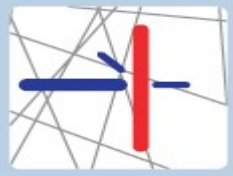
- Measurements 2013-present, F4E-FPA-395
- Fe and Cr – F4E final report, INDC(CZR)-0003,
- Cu and V - ND2016 proceedings
- (n,cp) – usually shorter lifetime (minutes), pneumatic post system
- Several channels lead to the same residual, eg. (n,α), (n,2n+2p), (n,2d) …
- Natural isotope composition

CS status in EXFOR

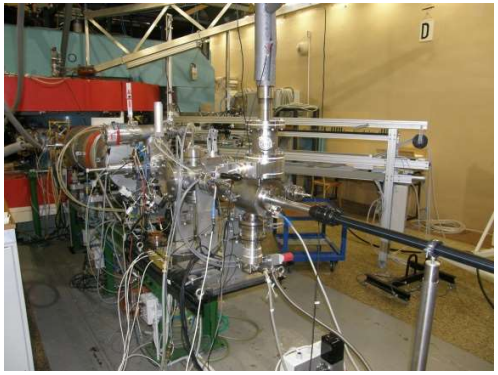




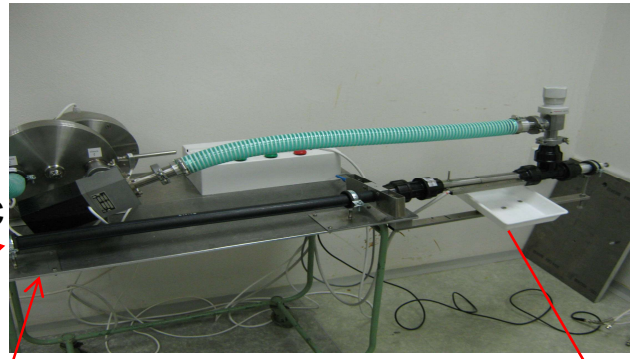
Neutron sources, pneupost



Li target station



6-7 sec

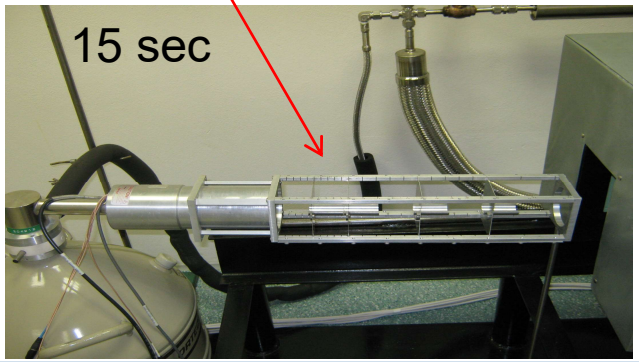


Pneumatic transport system

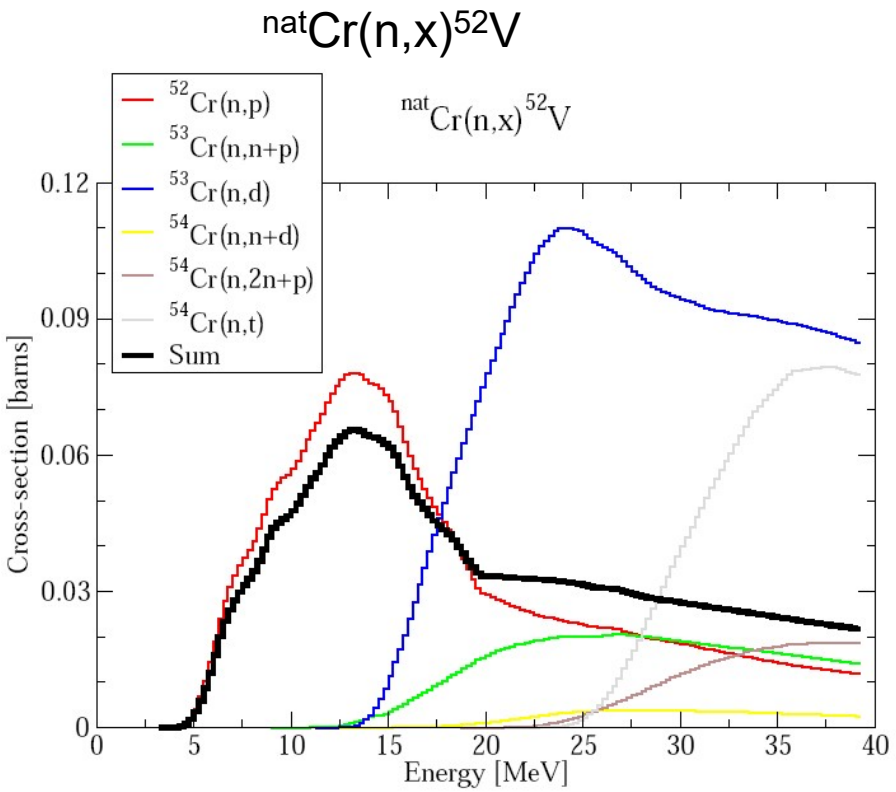
Be target station

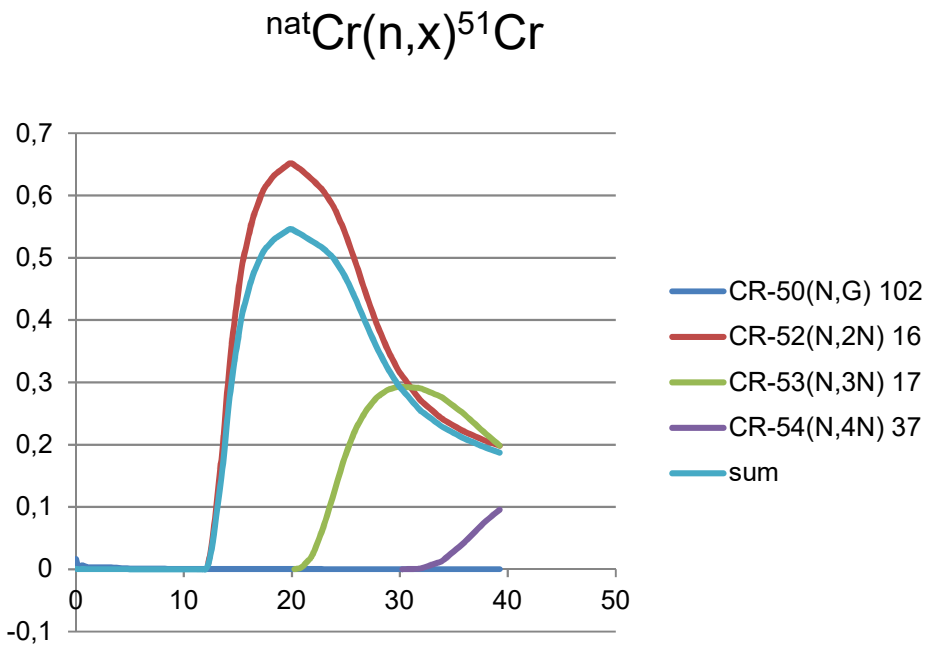
HPGe, timestamp acquisition

15 sec

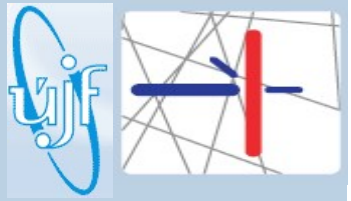


Used cross-sections – EAF-2010





TENDL-2015 & PREPRO



50Cr(n,n+d)48V

File: UNSHIELD.LST Line 381 Col 0 276288 bytes

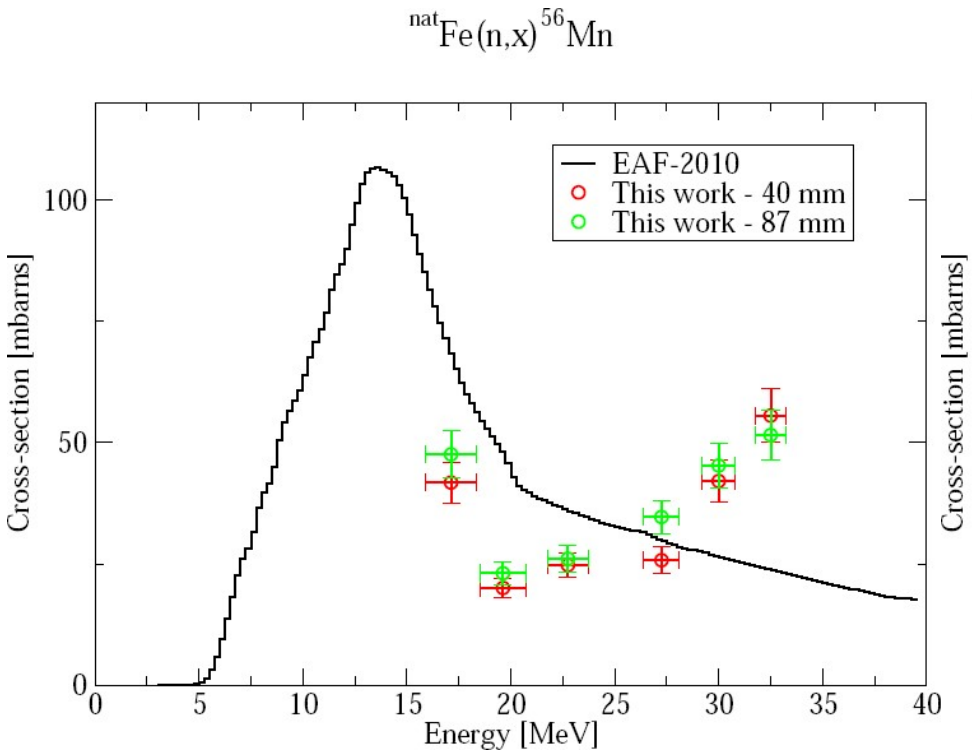
MT= 32

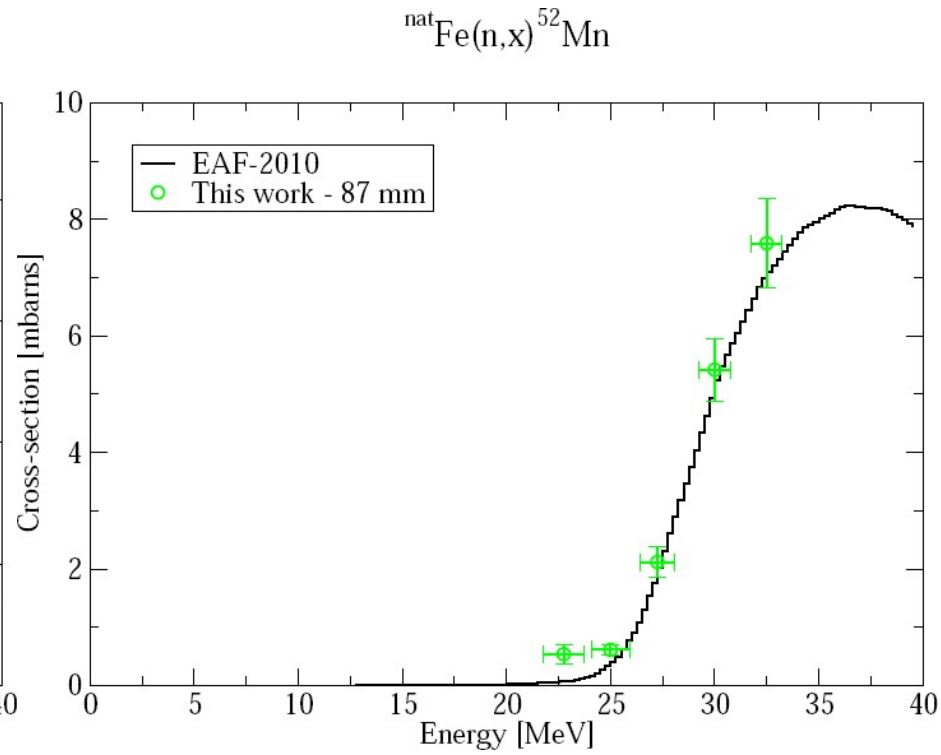
MAT 2425 0.0 Kelvin Unshielded Cross Sections 24-Cr-50

No.	Group-eV	Average	No.	Group-eV	Average	No.	Group-eV	Average	No.	Group-eV	Average
78	19250000.0	2.23915E-12	99	24500000.0	.004139695	120	29750000.0	.017426475	141	35000000.0	0.0
79	19500000.0	9.2761E-12	100	24750000.0	.004794705	121	30000000.0	0.0	142	35250000.0	0.0
80	19750000.0	1.64736E-11	101	25000000.0	.005481754	122	30250000.0	0.0	143	35500000.0	0.0
81	20000000.0	1.145618E-7	102	25250000.0	.006200842	123	30500000.0	0.0	144	35750000.0	0.0
82	20250000.0	3.436453E-7	103	25500000.0	.006919929	124	30750000.0	0.0	145	36000000.0	0.0
83	20500000.0	5.727288E-7	104	25750000.0	.007639017	125	31000000.0	0.0	146	36250000.0	0.0
84	20750000.0	8.018123E-7	105	26000000.0	.008337203	126	31250000.0	0.0	147	36500000.0	0.0
85	21000000.0	7.11141E-6	106	26250000.0	.009014488	127	31500000.0	0.0	148	36750000.0	0.0
86	21250000.0	1.950152E-5	107	26500000.0	.009691773	128	31				.0
87	21500000.0	3.189163E-5	108	26750000.0	.010369058	129	32				.0
88	21750000.0	4.428174E-5	109	27000000.0	.011030188	130	32				.0
89	22000000.0	1.327648E-4	110	27250000.0	.011675163	131	32500000.0	0.0	152	37750000.0	0.0
90	22250000.0	2.973409E-4	111	27500000.0	.012320138	132	32750000.0	0.0	153	38000000.0	0.0
91	22500000.0	4.61917E-4	112	27750000.0	.012965113	133	33000000.0	0.0	154	38250000.0	0.0
92	22750000.0	6.264931E-4	113	28000000.0	.013575338	134	33250000.0	0.0	155	38500000.0	0.0
93	23000000.0	9.329547E-4	114	28250000.0	.014150813	135	33500000.0	0.0	156	38750000.0	0.0
94	23250000.0	.001381302	115	28500000.0	.014726288	136	33750000.0	0.0	157	39000000.0	0.0
95	23500000.0	.001829649	116	28750000.0	.015301763	137	34000000.0	0.0	158	39250000.0	0.0
96	23750000.0	.002277996	117	29000000.0	.015851925	138	34250000.0	0.0	159	39500000.0	
97	24000000.0	.002829675	118	29250000.0	.016376775	139	34500000.0	0.0			
98	24250000.0	.003484685	119	29500000.0	.016901625	140	34750000.0	0.0			

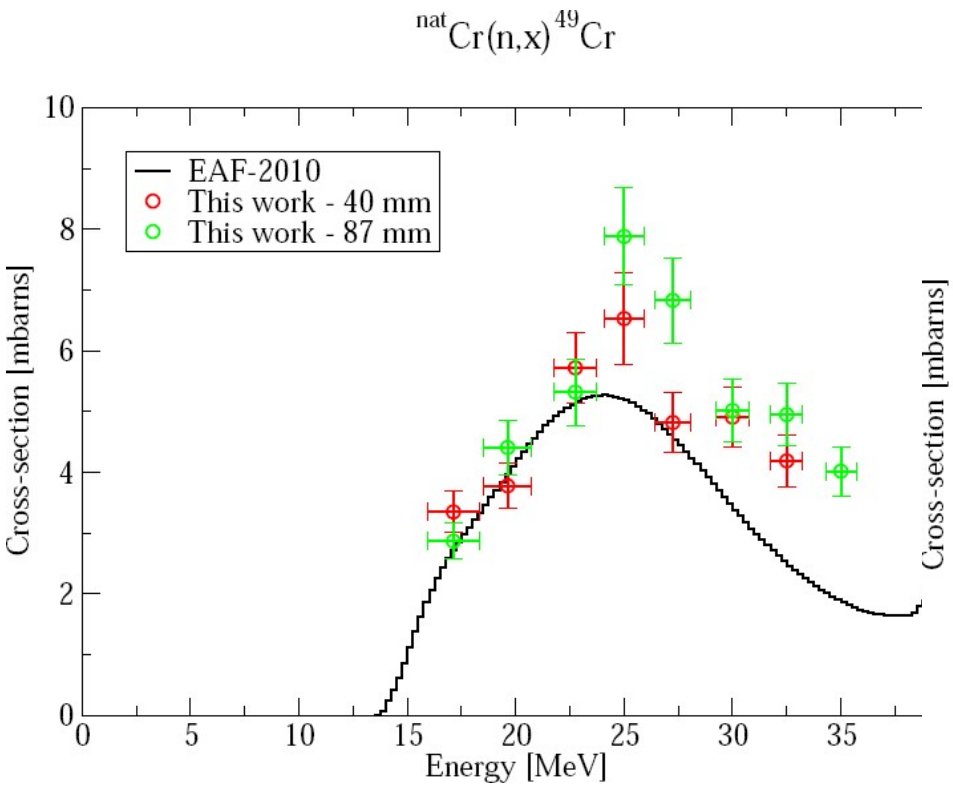
ZEROS above 30 MeV

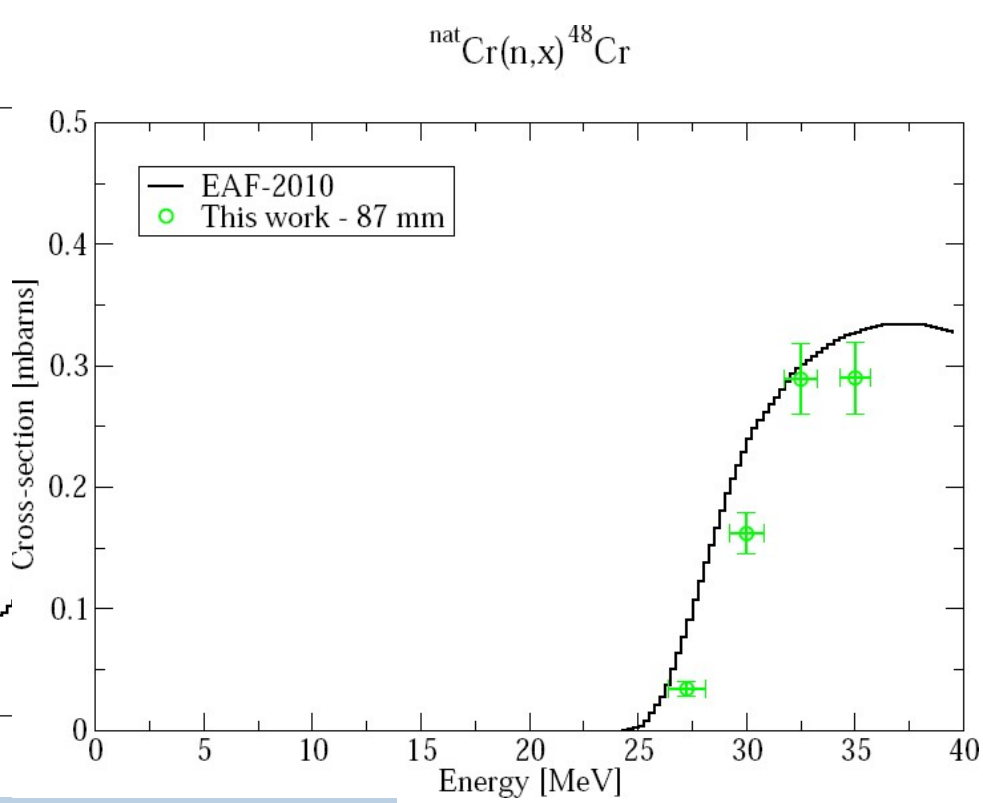
Fe and Cr


natFe(n,x)56Mn
EAF-2010
This work - 40 mm
This work - 87 mm
Cross-section [mbarns]
Energy [MeV]
0
50
100
0
5
10
15
20
25
30
35
40

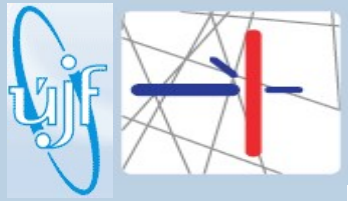

natFe(n,x)52Mn
EAF-2010
This work - 87 mm
Cross-section [mbarns]
Energy [MeV]
0
2
4
6
8
10
0
5
10
15
20
25
30
35
40

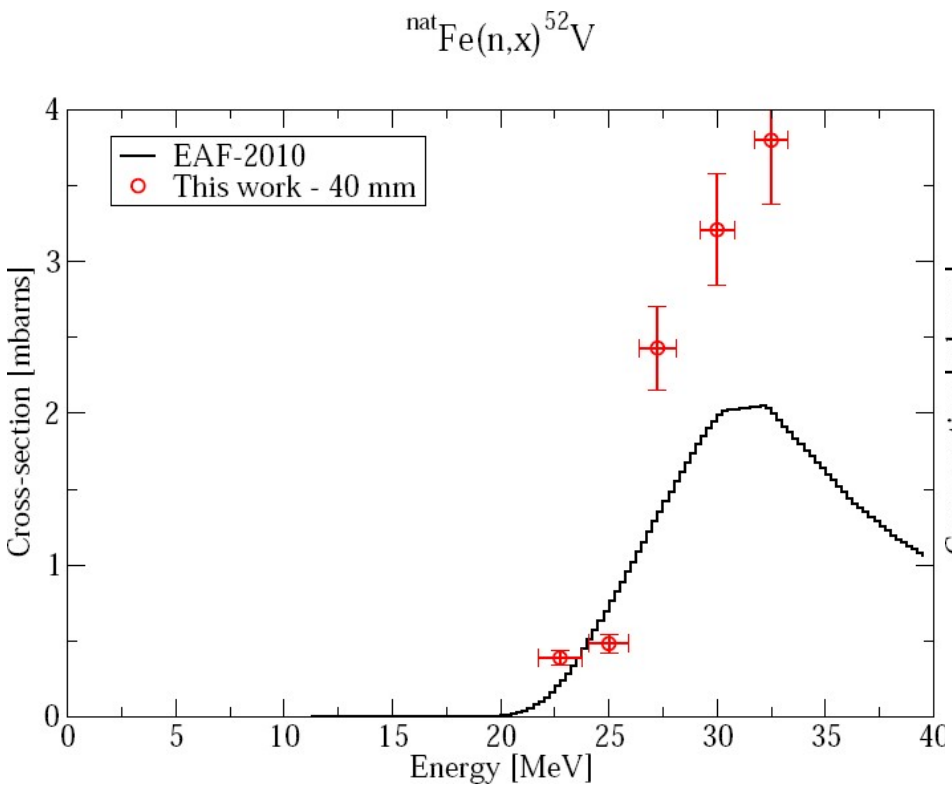
Fe and Cr

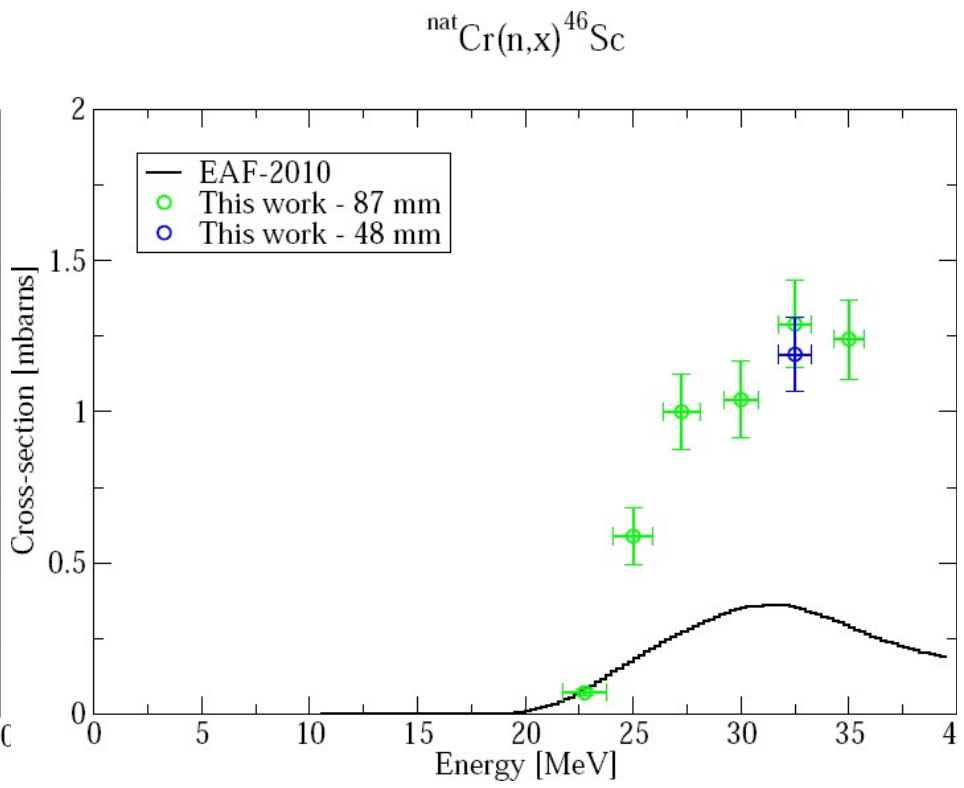

$^{nat}Cr(n,x)^{49}Cr$
EAF-2010
This work - 40 mm
This work - 87 mm
Cross-section [mbarns]
Energy [MeV]
0
2
4
6
8
10
0
5
10
15
20
25
30
35


$^{nat}Cr(n,x)^{48}Cr$
EAF-2010
This work - 87 mm
Cross-section [mbarns]
Energy [MeV]
0
0.1
0.2
0.3
0.4
0.5
0
5
10
15
20
25
30
35
40

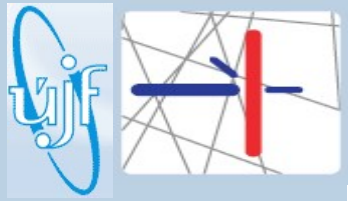
(n,p+α), Fe and Cr

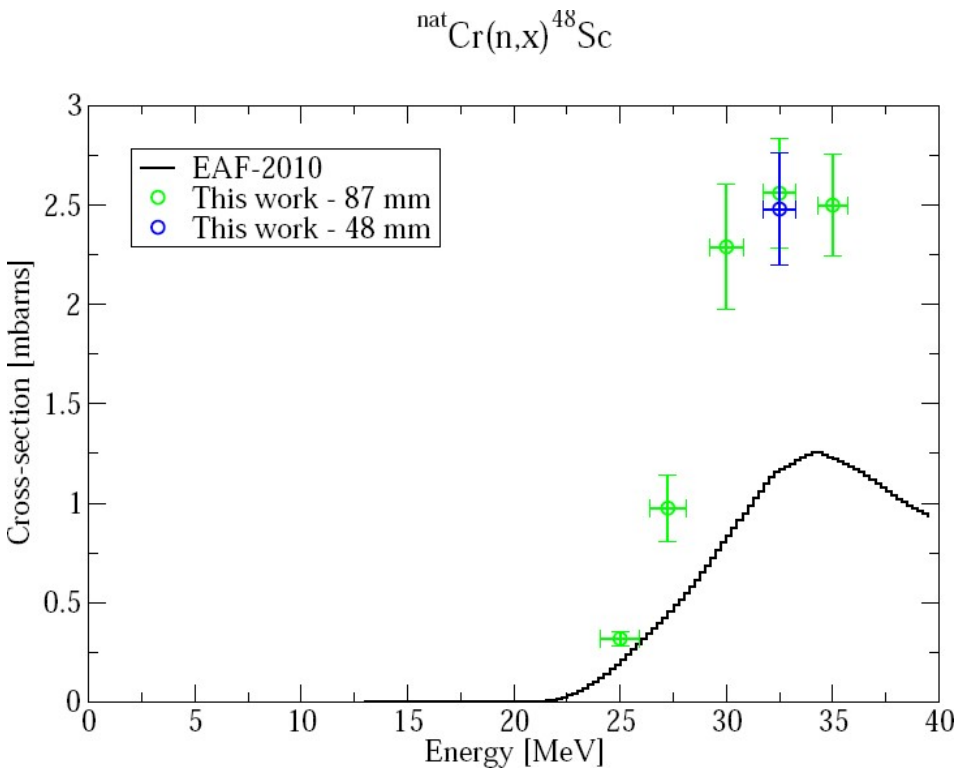


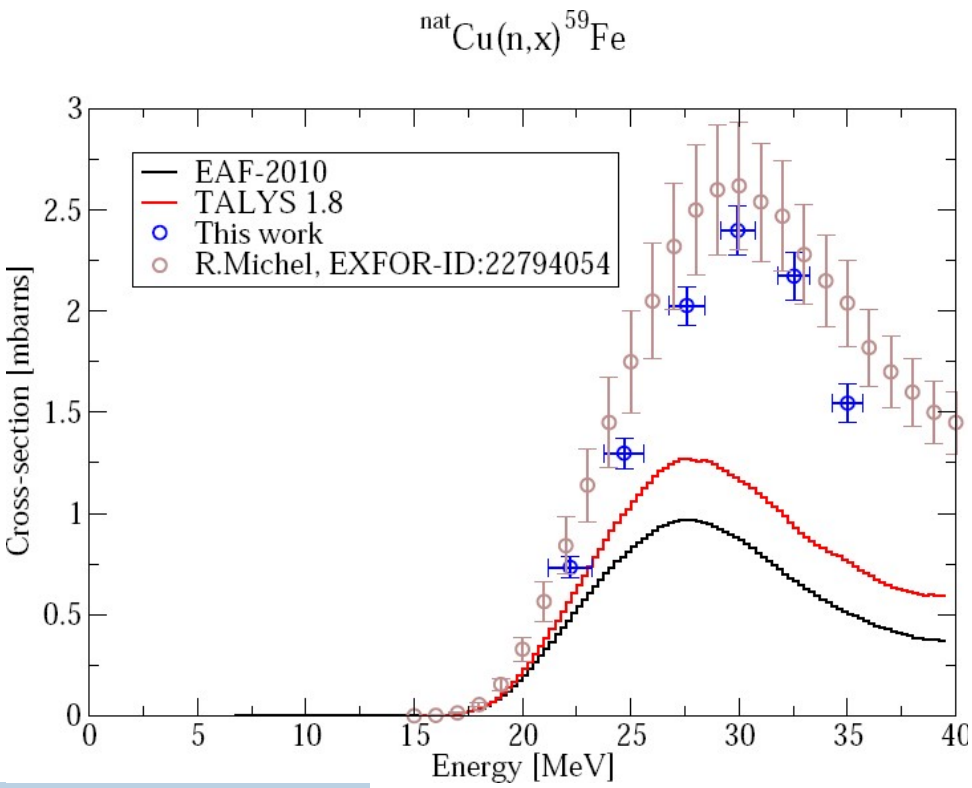

$^{nat}Fe(n,x)^{52}V$
EAF-2010
This work - 40 mm
Cross-section [mbarns]
Energy [MeV]
0
1
2
3
4
0
5
10
15
20
25
30
35
40


$^{nat}Cr(n,x)^{46}Sc$
EAF-2010
This work - 87 mm
This work - 48 mm
Cross-section [mbarns]
Energy [MeV]
0
0.5
1
1.5
2
0
5
10
15
20
25
30
35
4

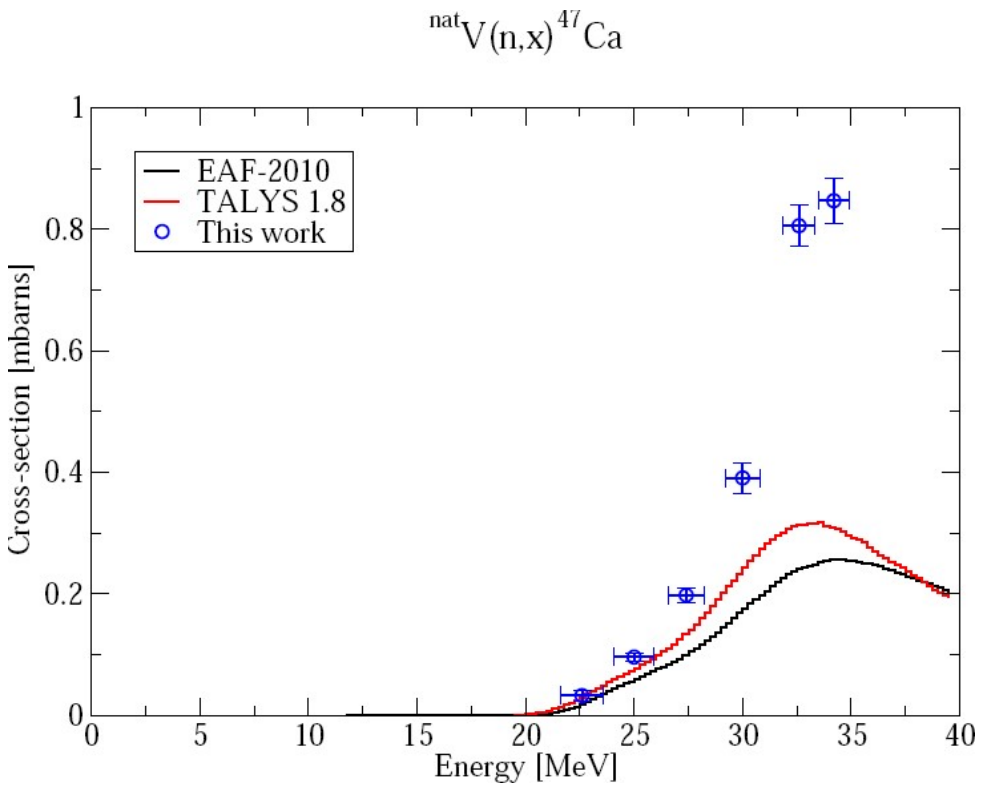
(n,p+α), Cr and Cu



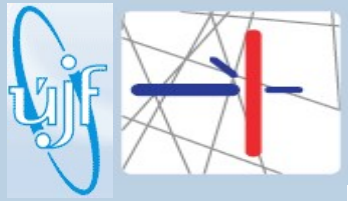

$^{nat}Cr(n,x)^{48}Sc$
EAF-2010
This work - 87 mm
This work - 48 mm
Cross-section [mbarns]
Energy [MeV]
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25
30
35
40


$^{nat}Cu(n,x)^{59}Fe$
EAF-2010
TALYS 1.8
This work
R.Michel, EXFOR-ID:22794054
Cross-section [mbarns]
Energy [MeV]
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25
30
35
40

(n,p+α), V

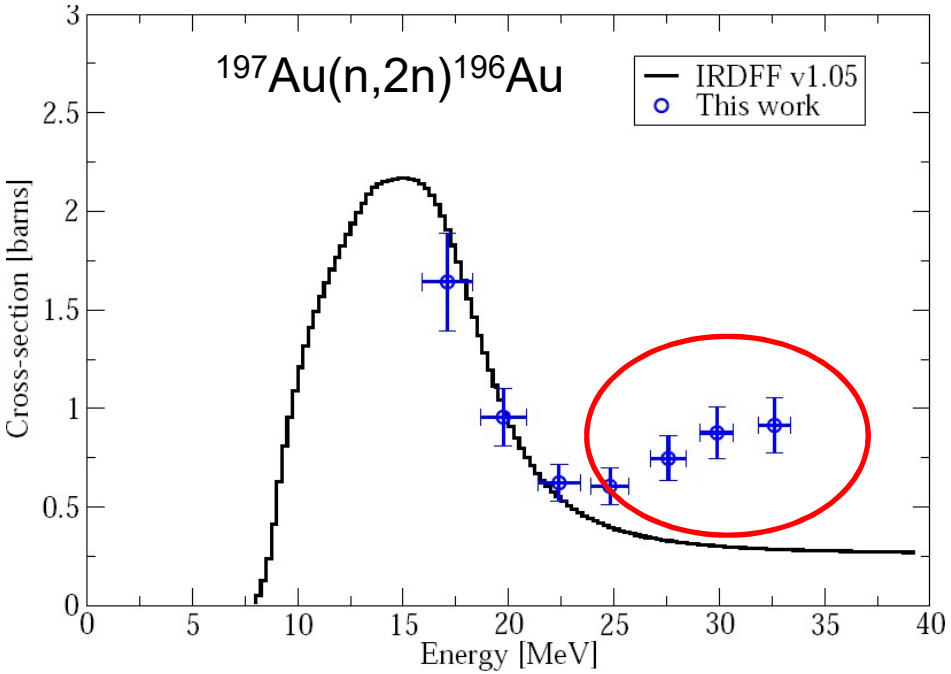

$^{nat}V(n,x)^{47}Ca$
EAF-2010
TALYS 1.8
This work
Cross-section [mbarns]
Energy [MeV]
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30
35
40

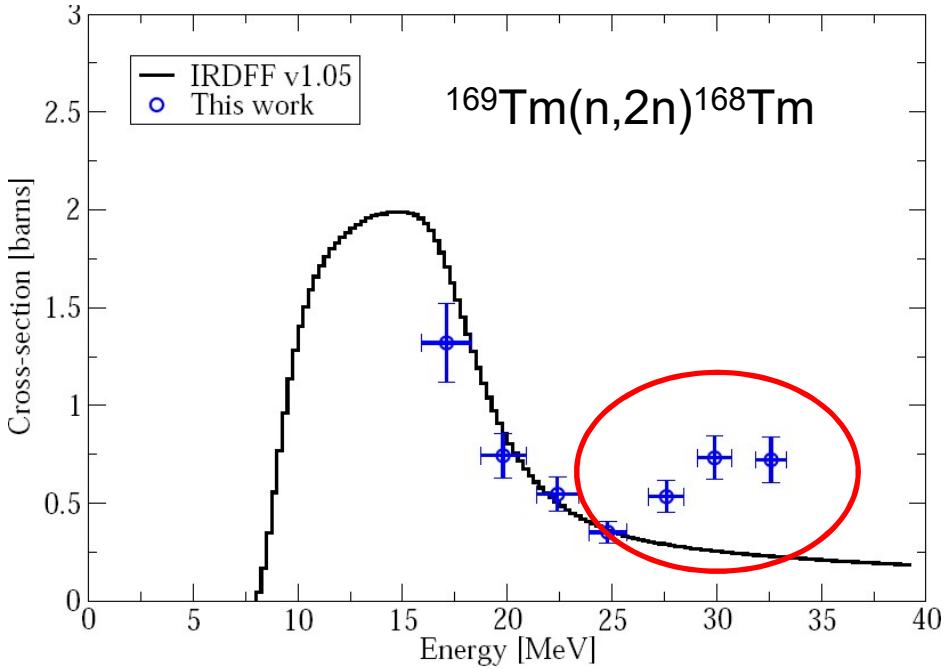
Au, Bi, Co, Fe, Tm – again and better



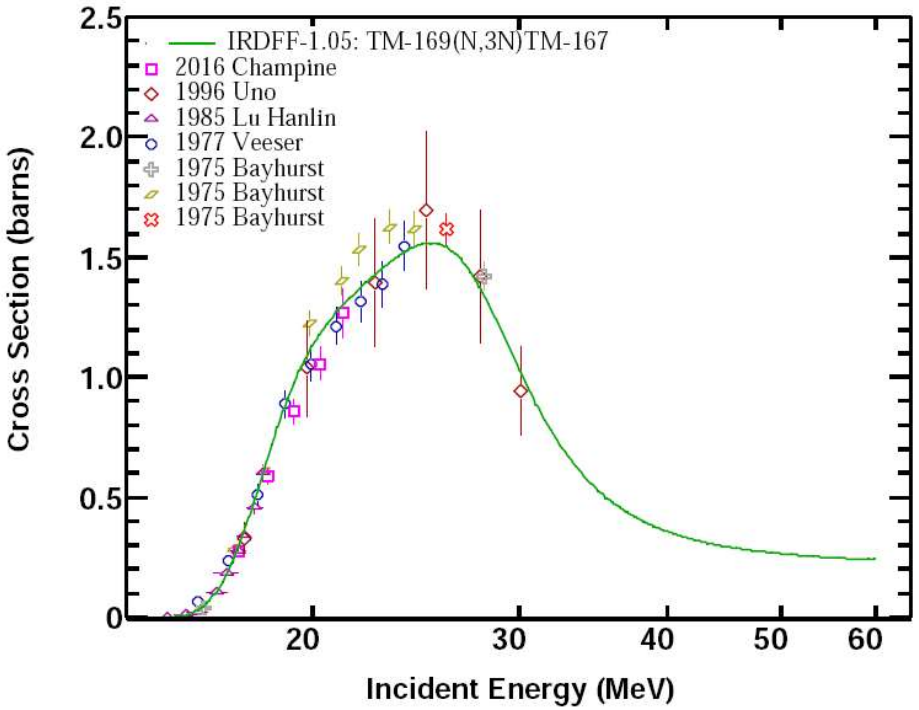
- IRDFF v1.05 benchmark
- Decrease uncertainties
- ^{nat}Li instead of ^{7}Li, direct normalization to ^{7}Be production
- Reevaluation of neutron spectra
- But results are so far not reflecting our efforts…

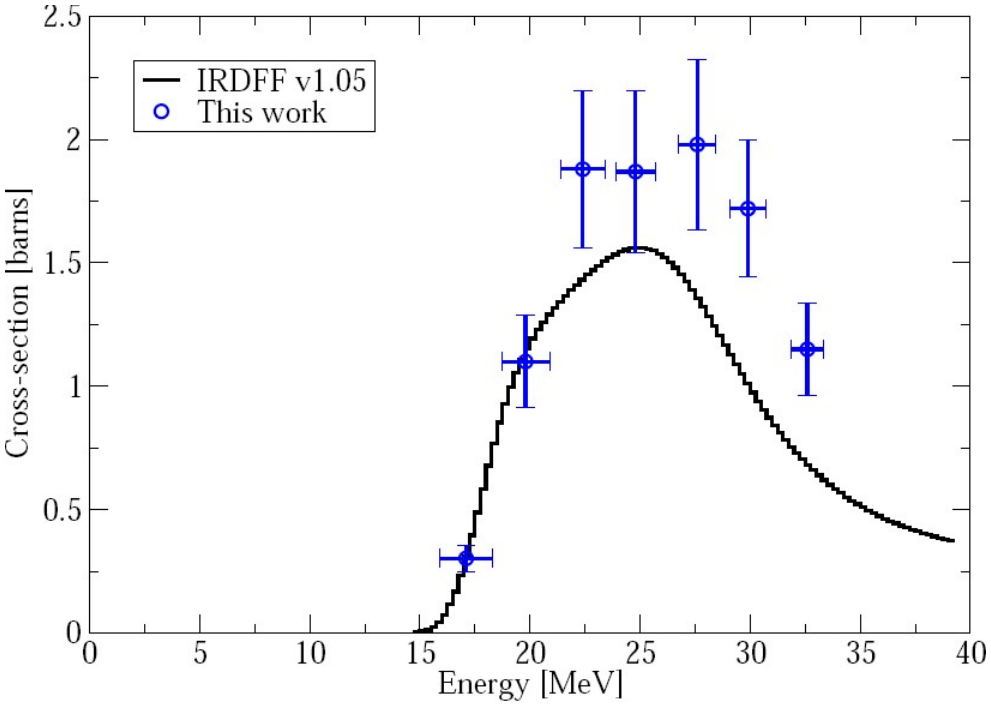
Au, Bi, Co, Fe, Tm – again and better



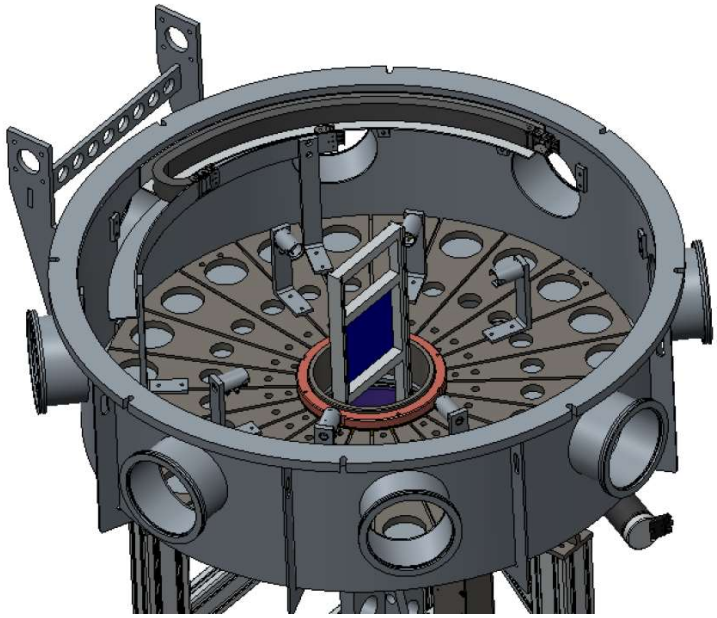


Au, Bi, Co, Fe, Tm – again and better

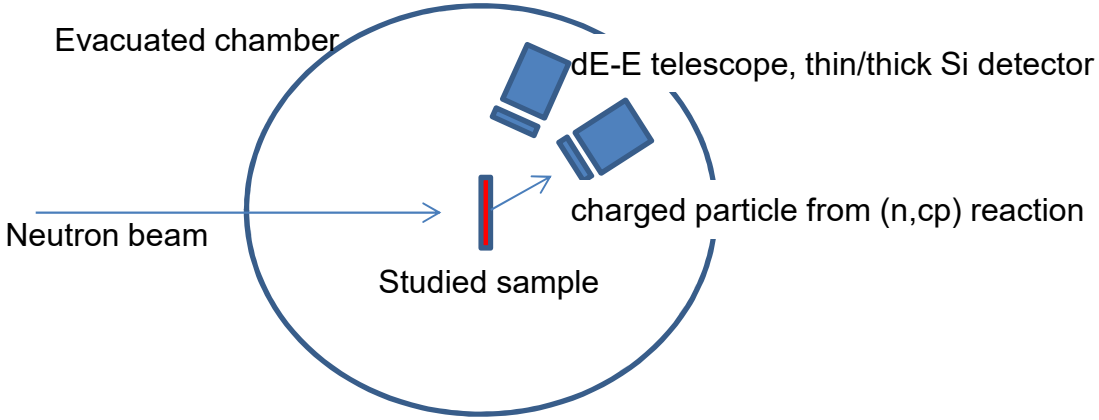




Detection of charged particles



Under construction at NPI

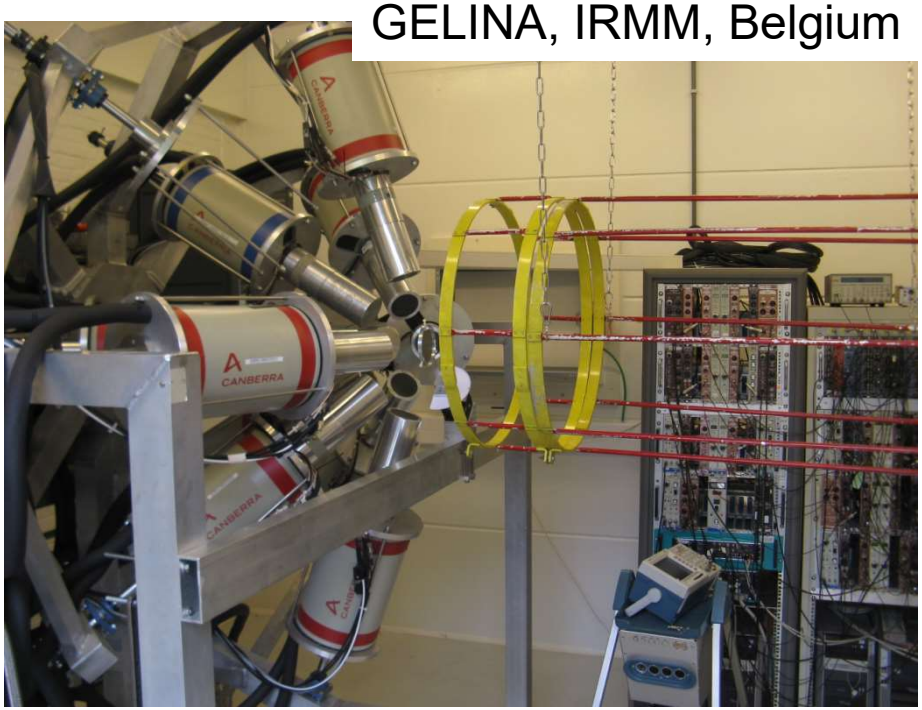


- Gas production in materials
- Direct detection of charged particles, complementary to residual detection with HPGe
- Charged particles lose energy in the sample
- Several QM n beams, unfolding for CS

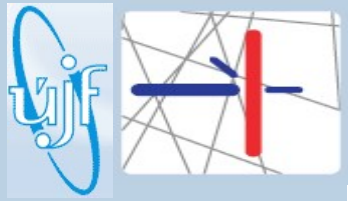
Online γ spectrometer

- (n,*γ) reactions
- ms-s isotopes – eg. $^{209}Bi(n,2n)^{208m}Bi$ in PbBi alloy
- Custom timing, U120M cyclotron driven by arduino
- Acquisition with CAEN digitizers
- Ready in 2018

GELINA, IRMM, Belgium



Conclusion



- EAF-2010 was used, TENDL/TALYS could be used
- Good agreement C/E, systematic deviation (n,p+α)
- CS are sensitivite to neutron spectrum uncertainty
- Always publish bare reaction rates for later reinterpretation!
- New p+Li evaluation in preparation (next talk)
- Uncertainties below 10%
- New online measurement possibilities in 2018-2019 (chamber for light ion detection, HPGe detector array)

Thank you