Recent EGAF Thermal Neutron Cross Section Measurements

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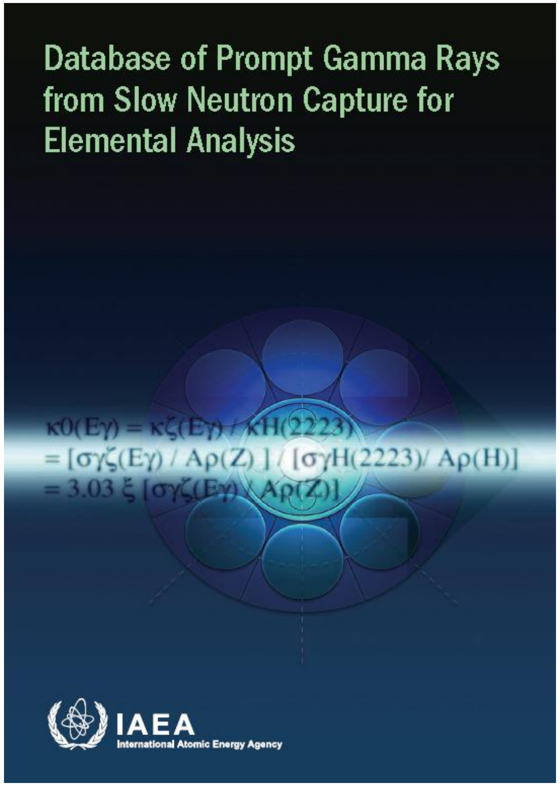


IAEA
International Atomic Energy Agency

BERKELEY LAB

Evaluated Gamma-ray Activation File (EGAF)

1999-2004: IAEA CRP on "Development of a Database for Prompt Gamma-ray Neutron Activation Analysis“

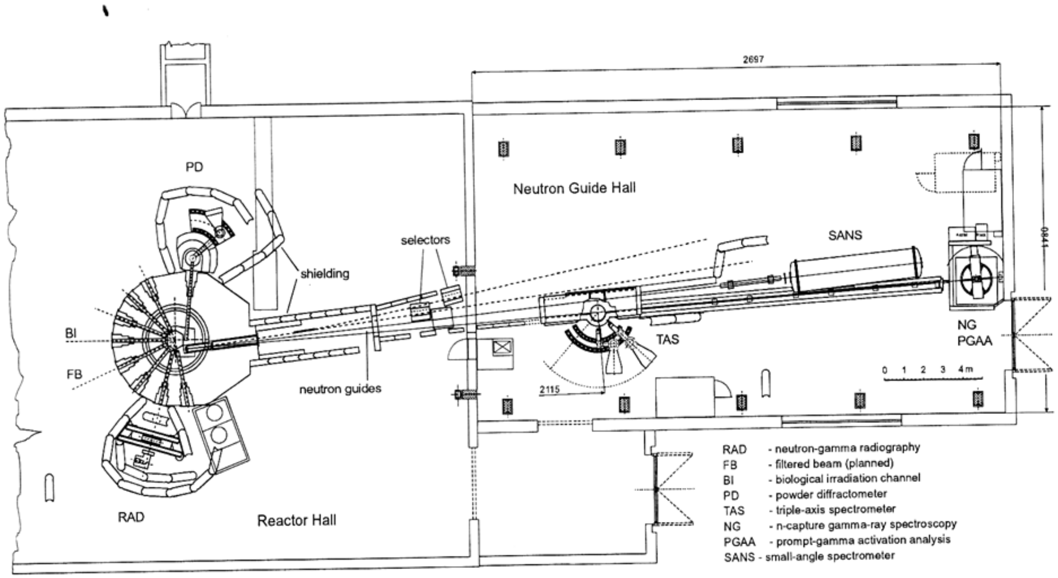
- Evaluation of thermal neutron capture prompt γ-ray cross sections for all elements with Z=1-83,90,92 except He and Pm.
- Measurements perfomed at the Budapest Reactor
- Determined prompt and delayed E_γ, σ_γ, σ_0, level schemes and S_n

2004: Published *Handbook of Prompt Gamma Activation Analysis*, Kluwer Publishers.

2007: Published *Database of Prompt Gamma Rays from Slow Neutron Capture for Elemental Analysis*, IAEA STI/PUB/1263.

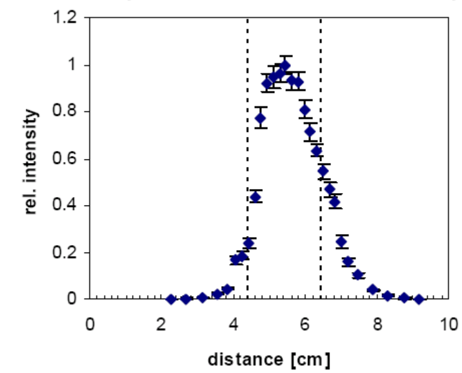
>2007: Continued (n,γ) measurements on enriched isotopic targets at the Budapest and FRM-II (Garching) reactors.

Measurements



Guided, curved neutron beam

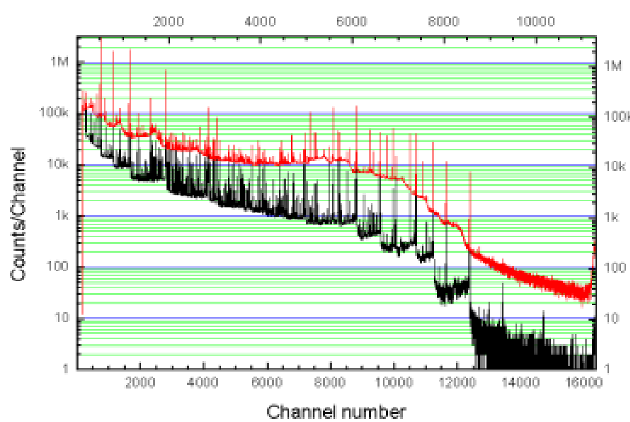
Prompt γ-rays were measured ≈30 m from the reactor wall in a low background counting area.



Measured beam profile

Thermal flux: 2×10^6 cm^{-2}s^{-1}.

Cold flux: 5×10^7 cm^{-2}s^{-1}



HPGe: Compton suppressed γ-ray spectrum for CCl_4

Efficiency: <1% for E=0.5-6 MeV, <3% for 6-10 MeV

The Budapest neutron beam is a pure cold/thermal beam with no fast component!

Standardization

Thermal γ-ray cross sections were determined using internal standards of known composition. For 1/v isotopes this measurement is independent of neutron energy. For non-1/v isotopes g-factor corrections were made.

1. **Stoichiometric compounds** containing elements with well-known cross sections: **B, H, N, Cl, S, Na, Ti, Au**

   e.g. KCl, $(CH_2)_n$, $Pb(NO_3)_2$, GdB_6, Tl_2SO_4
2. **Homogenous mixtures**

   Aqueous (H_2O) or acid (20% HCl) solutions, mixed powders (TiO_2)
3. **Activation products** with well-known decay P_γ

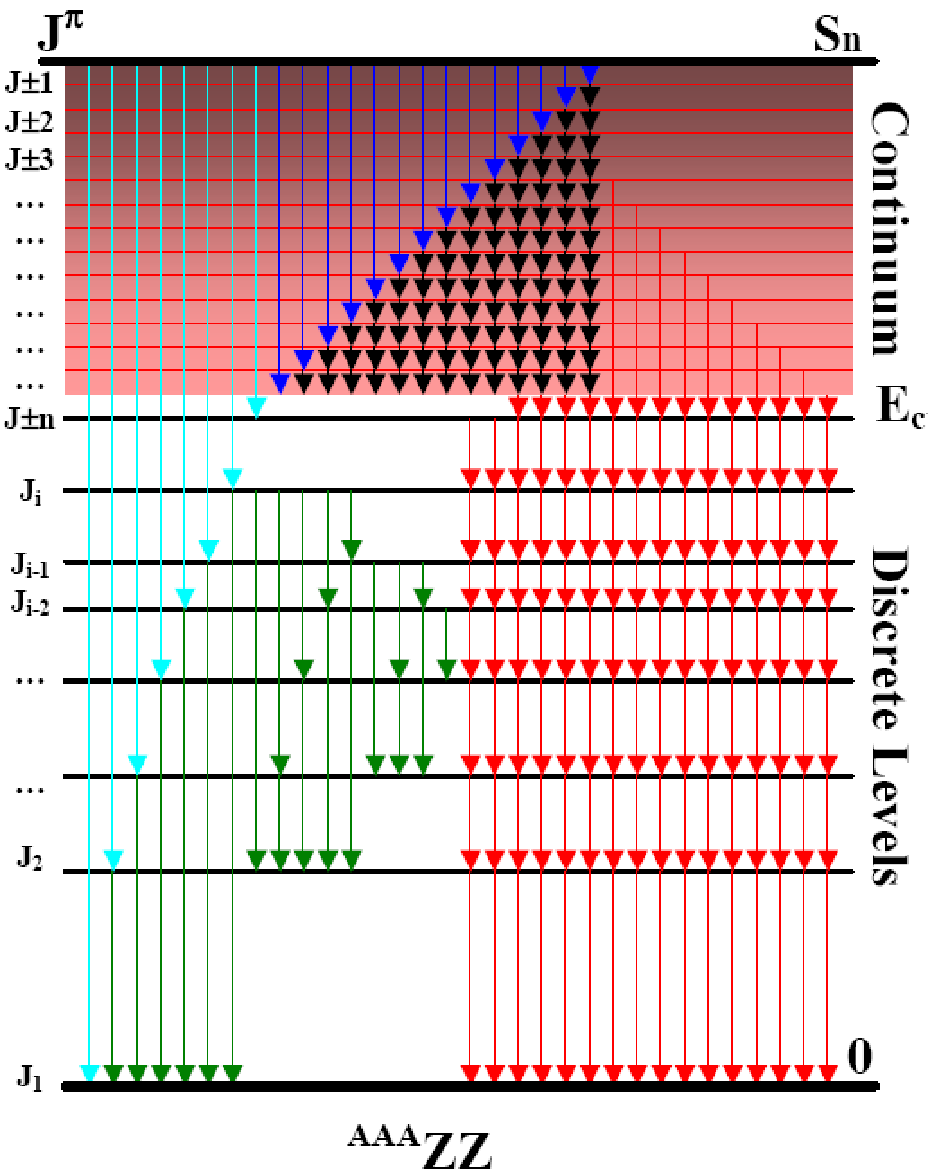
   ^{19}F, ^{28}Al, ^{100}Tc, ^{235}U

Measurements were performed on all elemental targets with

Z=1-83, 92 except for He and Pm

and on the selected radioactive targets ^{99}Tc, and ^{129}I.

Determination of σ_0



For **low-Z** complete (n,γ) decay schemes are measured in EGAF and

$$\sigma_0 = \Sigma\sigma_\gamma(GS) = \Sigma\sigma_\gamma(CS)$$

For **high-Z**, when the (n,γ) continuum feeding is significant,

$$\sigma_0 = \Sigma\sigma_\gamma(GS)^{EGAF}_{E<E_{crit}} + \Sigma\sigma_\gamma(GS)^{cont}_{E>E_{crit}}$$

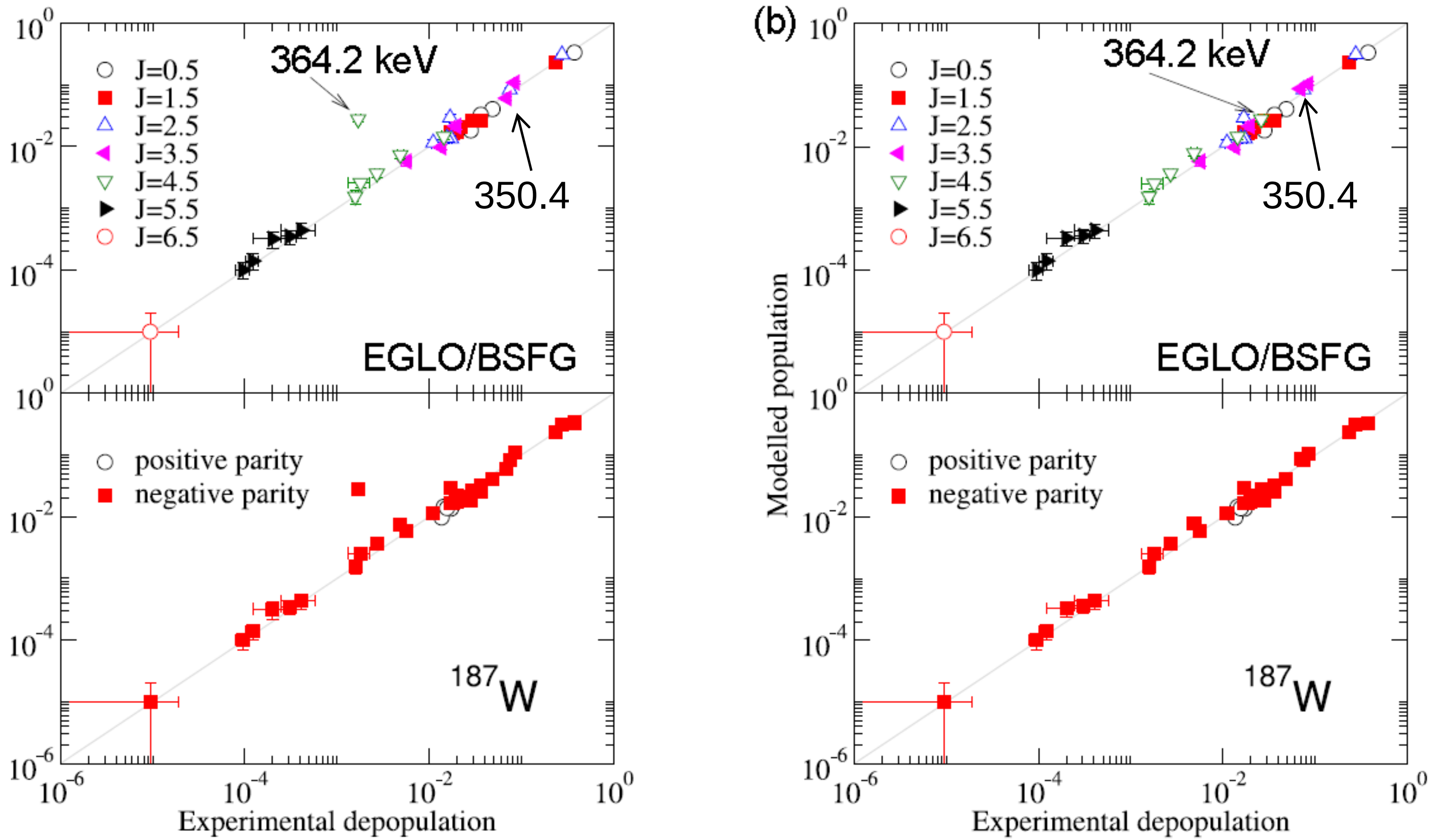
E_{crit} is the excitation energy up to which the level scheme is complete.

We use the DICEBOX* statistical model code to calculate continuum feeding to the GS.

- DICEBOX calculates multiple decay scheme "realizations" to estimate inherent statistical variations.
- Numerous photon strength and level density models are available.
- Calculated feeding to excited states below Ecrit is normalized to EGAF cross section deexciting these levels.

*F. Becvar and M. Krticka, Charles University, Prague.

Population/Depopulation Plot



- Calculated population of levels below E_{crit} for ^{187}W agrees well with EGAF cross section deexciting these levels over 5 orders of magnitude in intensity.
- Disagreement for 364.2-keV $9/2^{-}$ level resolved by addition of 13.8 keV γ-ray to 350.4-keV $7/2^{-}$ level improving the fit to both levels.
- Population/depopulation plots are only weakly model dependent.

EGAF Evaluation Status

Publications (47 isotopes)

- Z=1-17 (25 isotopes) – Proceedings of ND2013
- ^{23}Na(n,γ) – submitted to Phys. Rev. C.
- ^{39,40,41}K(n,γ) – Phys. Rev. C 87, 024605 (2013).
- ^{102,104,105,106,108,110}Pd(n,γ) – Phys. Rev. C 77, 054615 (2008).
- ^{152,154}Eu(n,γ) – Proceedings of ND2013
- ^{155,157}Gd(n,γ) – Nucl. Sci. Eng. In press.
- ^{182,183,184,186}W(n,γ) – submitted to Phys. Rev. C.

Evaluations in progress (13 isotopes)

- ^{54,56,57,58}Fe(n,γ) – Firestone, Krticka
- ^{89}Y(n,γ) – Abusaleem, Hurst
- ^{93}Nb,^{103}Rh(n,γ) – Turkoghu*, Basunia
- ^{139}La(n,γ) – Ureche†, Hurst
- ^{180}W(n,γ) – Hurst
- ^{185}Re(n,γ) – Lerch*, Hurst, Carroll
- ^{237}Np,^{241}Am,^{242}Pu(n,γ) – Genreith*, Hurst
- ^{238}U(n,γ) – Basunia, Genreith*, Sleaford

Recent Measurements (Garching FRM-II)

- ^{70,72,74,76}Ge, ^{90,91,92,94}Zr, ^{192,196,198}Pt(n,γ) – Firestone, Oslo Group

* Graduate student, † Undergraduate student

^{23}Na,^{39,40,41}K(n,γ)

^{23}Na: R.B. Firestone et al, submitted to Phys. Rev. C.(2103)
^{39,40,41}K: R.B. Firestone et al, Phys. Rev. C 87, 024605 (2013)

Isotope	σ_0 (b) Atlas*	σ_0 (b) This work
^{23}Na	0.541(3)	0.517(4)
^{39}K	2.1(2)	2.28(4)
^{40}K	30(8)	90(7)
^{41}K	1.46(3)	1.62(3)

E_γ (^{41}K)	P_γ ENSDF	P_γ This work
1524.7	0.1808(9)	0.164(4)

*Atlas of Neutron Resonances, S.F. Mughabghab, Elsevier (2006).

New Potassium Nuclear Structure Data				
Isotope	^{23}Na	^{40}K	^{41}K	^{42}K
# levels below E_{crit} (RIPL)†	4	15	11	4
# levels below E_{crit} (This work) †	13	21	16	17
New J^{π} assignments	21	3	2	8
New levels placed	0	18	0	0
Previous levels removed	0	1	0	0
New γ-rays placed	27	2	0	0

† E_{crit} is the excitation energy where the level scheme is complete.

$^{182,183,184,186}W(n,\gamma)$

A.M. Hurst, et al, submitted to Phys. Rev. C.

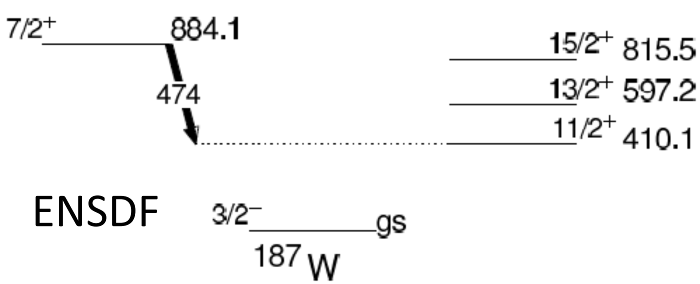
Tungsten Thermal (n,γ) Cross Sections		
Isotope	**Cross section (b)**	
	This work	**Atlas**
$^{182}W(n,\gamma)^{183}W$	20.5(14)	19.9(3)
$^{182}W(n,\gamma)^{183}W^m$	0.177(18)	---
$^{183}W(n,\gamma)^{184}W$	9.4(4)	10.4(2)
$^{183}W(n,\gamma)^{184}W^m$	0.025(6)	---
$^{184}W(n,\gamma)^{185}W$	1.43(10)	1.7(1)
$^{184}W(n,\gamma)^{185}W^m$	0.0062(16)	---
$^{186}W(n,\gamma)^{187}W$	33.3(6)	38.1(5)
$^{186}W(n,\gamma)^{187}W^m$	0.400(16)	---

^{187}W $\beta-$ decay P_γ(686 keV)	
This work	0.352(9)
ENSDF	0.332(5)

Tungsten Neutron Separation Energy		
Isotope	**S_n (keV)**	
	This Work	**AME**
^{183}W	6190.88(6)	6190.81(5)
^{184}W	7411.11(13)	7411.66(25)
^{185}W	5753.74(5)	5753.71(30)
^{187}W	5466.62(7)	5466.79(5)

Improved W Adopted Level, Gamma Data

New Tungsten Nuclear Structure Data				
Isotope	^{183}W	^{184}W	^{185}W	^{187}W
# levels below E_{crit} (RIPL)	11	12	8	3
# levels below E_{crit} (This work)	12	18	11	40
New J^{π} assignments	1	1	3	16
New levels placed	0	0	0	1
Previous levels removed	1	1	0	0
New γ-rays placed	1	2	2	5



ENSDF

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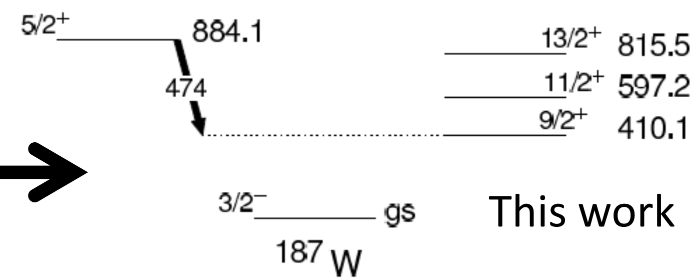

This work

J^{π} of -26.6 eV bound resonance	
ENSDF	$(0,1)^{-}$
This work	1^{-}

$^{152,154}Eu$, $^{155,157}Gd(n,\gamma)$

^{152,154}Eu: Proceedings of ND2013
^{155,157}Gd: Nucl. Sci. Eng. In press.

Tungsten Thermal (n,γ) Cross Sections		
Isotope	**Cross section (b)**	
	This work	**Atlas**
$^{152}Eu(n,\gamma)^{153}Eu^{g}$	7060(400)	5900(200)
$^{152}Eu(n,\gamma)^{153}Eu^{m1}$	2345(220)	3300(200)
$^{152}Eu(n,\gamma)^{184}Eu^{g+m1}$	9405(460)	9200(100)
$^{154}Eu(n,\gamma)^{155}Eu^{m}$	335(10)	310(7)
$^{155}Gd(n,\gamma)^{156}Gd$	56,700(2100)	60,900(500)
$^{157}Gd(n,\gamma)^{158}Gd$	239,000(6000)	254,000(815)

Discrepancy in $^{153}Eu^{m1}$ cross section due to decay scheme normalization

$Z \leq 17$ (n,γ)

Target	$\sigma_0 0$(EGAF)	σ_0(Atlas*)
^{6}Li	52.6(22) mb	44.8(3) mb
^{7}Li	46.3(13) mb	45.2(14) mb
^{9}Be	8.8(6) mb	8.5(3) mb
^{10}B	3.90(11) mb	3.05(16) mb
^{11}B	9.06(20) mb	5.5(33) mb
^{12}C	3.89(6) mb	3.53(7) mb
^{13}C	1.51(3) mb	1.37(4) mb
^{14}N	78.5(7) mb	80.1(6) mb
^{15}N	39(3) mb	24(8) mb
^{16}O	197(7) mb	190(20) mb
^{19}F	9.63(16) mb	9.51(9) mb
^{23}Na	541(3) mb	517(4) mb
^{24}Mg	535(20) mb	538(13) mb
^{25}Mg	196(8) mb	199(3) mb
^{26}Mg	38.8(14) mb	38.4(6) mb
^{27}Al	232.2(17) mb	231(3) mb
^{28}Si	186(2) mb	171(3) mb
^{29}Si	128(4) mb	119(3) mb
^{30}Si	112(6) mb	107(2) mb
^{31}P	169(5) mb	165(3) mb
^{32}S	542(7) mb	518(14) mb
^{33}S	449(7) mb	454(20) mb
^{34}S	285(8) mb	256(9) mb
^{35}Cl	44.00(20) b	43.6(4) b
^{37}Cl	50.0(8) mb	43.3(6) mb

Measurements published in the proceedings of ND2013.

Complete decay schemes available for all isotopes.

THANK YOU
FOR
YOUR
ATTENTION!
ANY QUESTIONS?