Dzysiuk Nataliya and Kadenko Igor

Experimental determination of (n,x) cross sections on germanium (Ge), terbium (Tb) and lutetium (Lu)

Workshop on Nuclear reaction Data for Advanced Reactor Technologies

19-30 May 2008 Trieste

Taras Shevchenko National University of Kiev

Reasons why cross sections are necessary

Current importance and applications

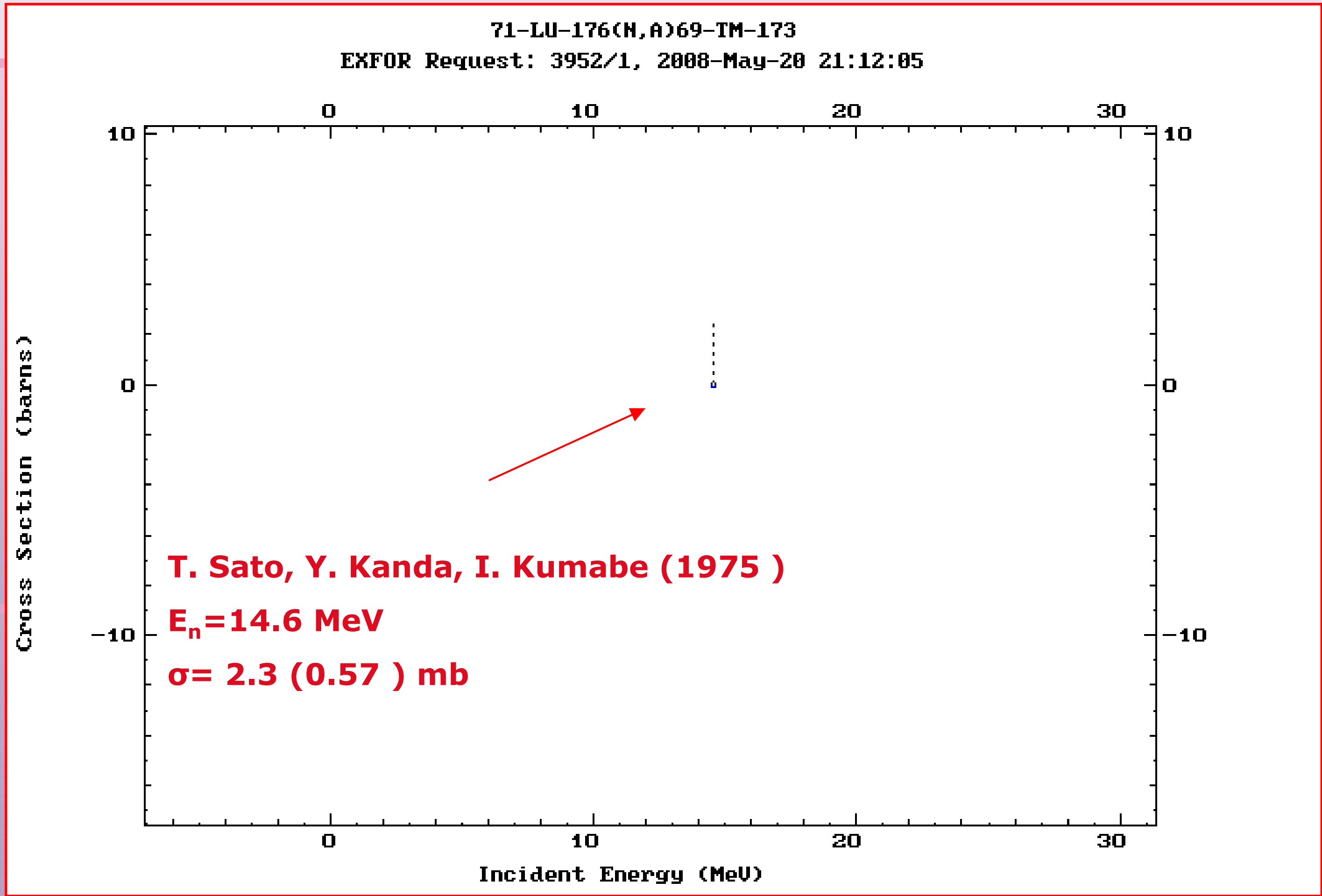
http://www-nds.iaea.org/exfor/exfor00.htm

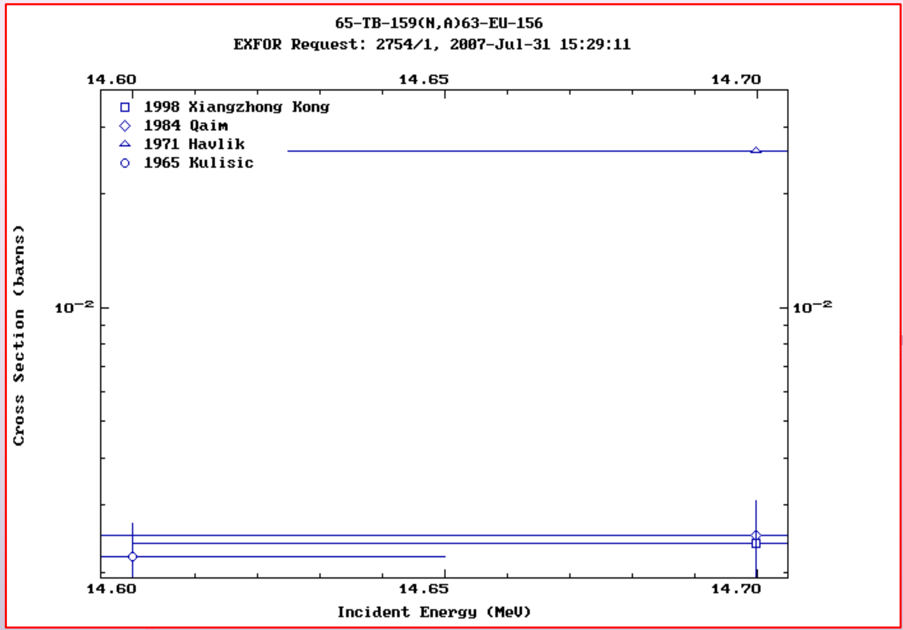
- Incompleteness of EXFOR database **NO DATA FOUND**

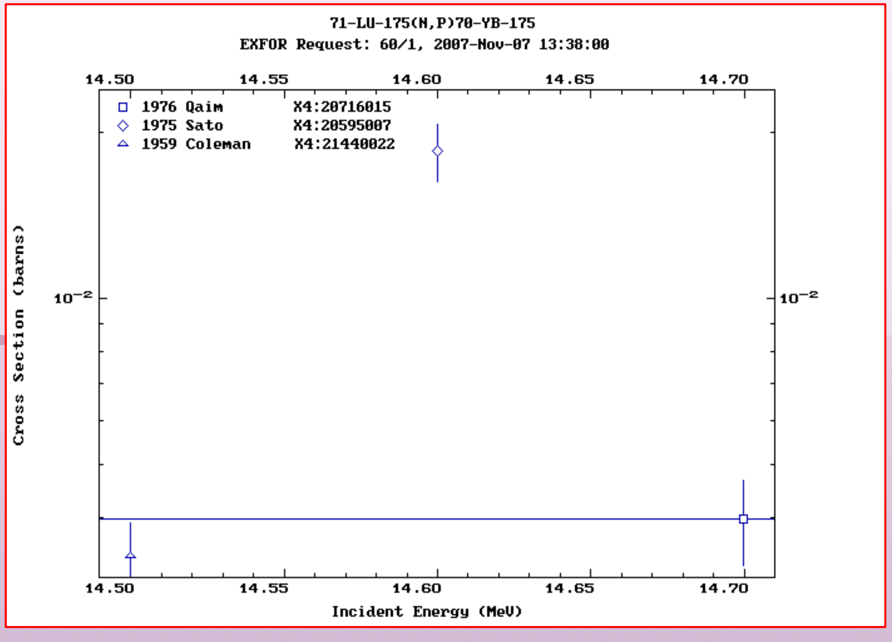
$\boxed{{}^{72}Ge(n,2n)^{71}Ge}$ $\boxed{{}^{175}Lu(n,\alpha)^{172}Tm}$ $\boxed{{}^{176}Lu(n,\alpha)^{173}Tm}$

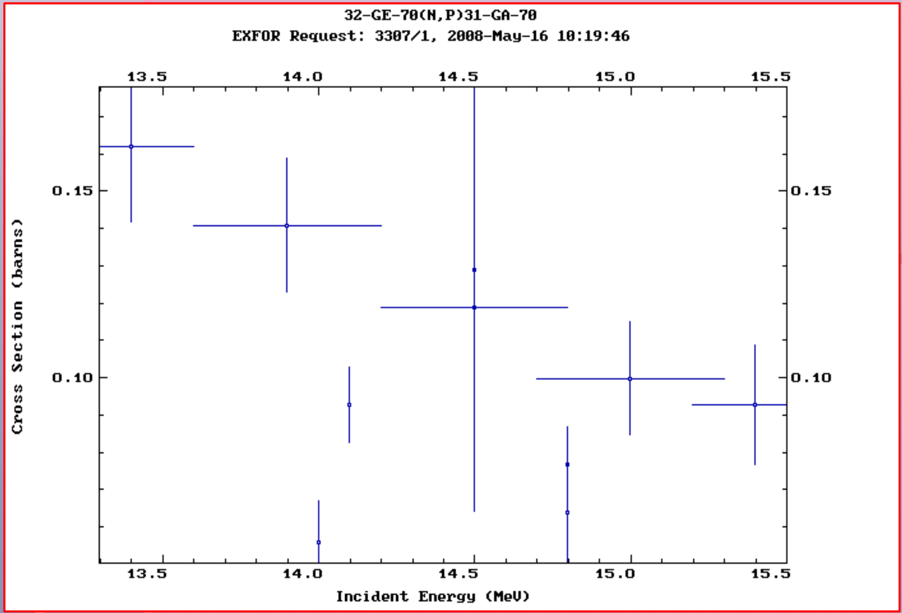
- Discrepancy in cross section values

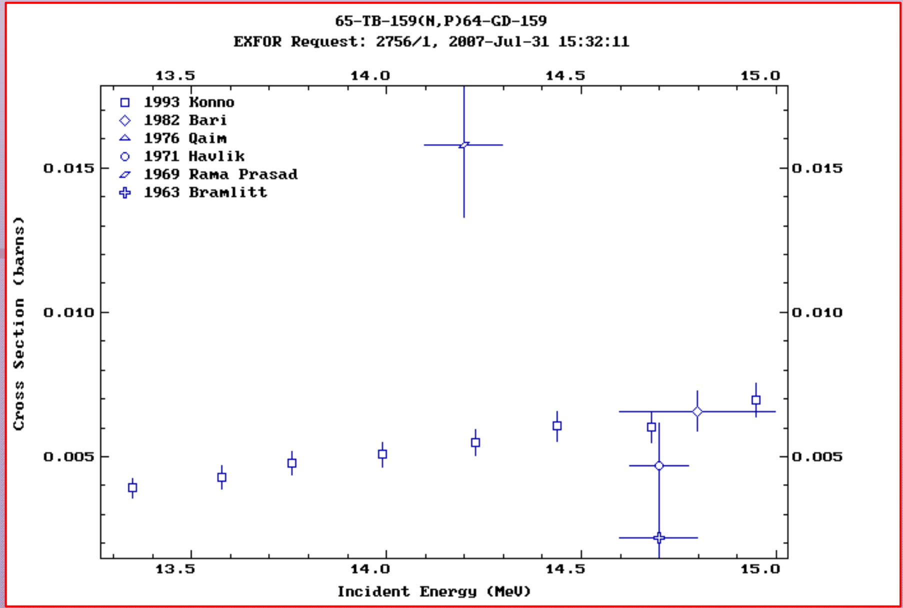
Reasons why cross sections are necessary




65-TB-159(N,A)63-EU-156
EXFOR Request: 2754/1, 2007-Jul-31 15:29:11
1998 Xiangzhong Kong
1984 Qaim
1971 Havlik
1965 Kulisic
Cross Section (barns)
Incident Energy (MeV)


71-LU-175(N,P)70-YB-175
EXFOR Request: 60/1, 2007-Nov-07 13:38:00
1976 Qaim X4:20716015
1975 Sato X4:20595007
1959 Coleman X4:21440022
Cross Section (barns)
Incident Energy (MeV)


32-GE-70(N,P)31-GA-70
EXFOR Request: 3307/1, 2008-May-16 10:19:46
Cross Section (barns)
Incident Energy (MeV)


65-TB-159(N,P)64-GD-159
EXFOR Request: 2756/1, 2007-Jul-31 15:32:11
1993 Konno
1982 Bari
1976 Qaim
1971 Havlik
1969 Rama Prasad
1963 Bramlitt
Cross Section (barns)
Incident Energy (MeV)

Requirements of cross sections for applications

- Testing of nuclear reaction codes
- Geophysics (nuclear microanalysis of materials)
- Astrophysics
- Nuclear medicine
- Improvement of experimental information for data for providing reliability of neutron calculations in power engineering (advanced nuclear reactor plants)
- Transmutation of radioactive waste

Subject and purposes of investigations

Purpose of the investigations:

- **Independent measurements of neutron cross sections**
- **More precise definition of existing data for neutron cross sections at energy of 14.5 MeV**
- **Obtained new experimental values of cross section**

R. Forrest EURATOM/UKAEA Fusion Association, Culham Science Center,
Abington,Oxon OX14 3DB, UK
Fusion Engineering and Design 81 (2006) 2157-2174
“Data requirements for neutron activation” Part I: Nuclear data
“Data requirements for neutron activation” Part II: Decay data

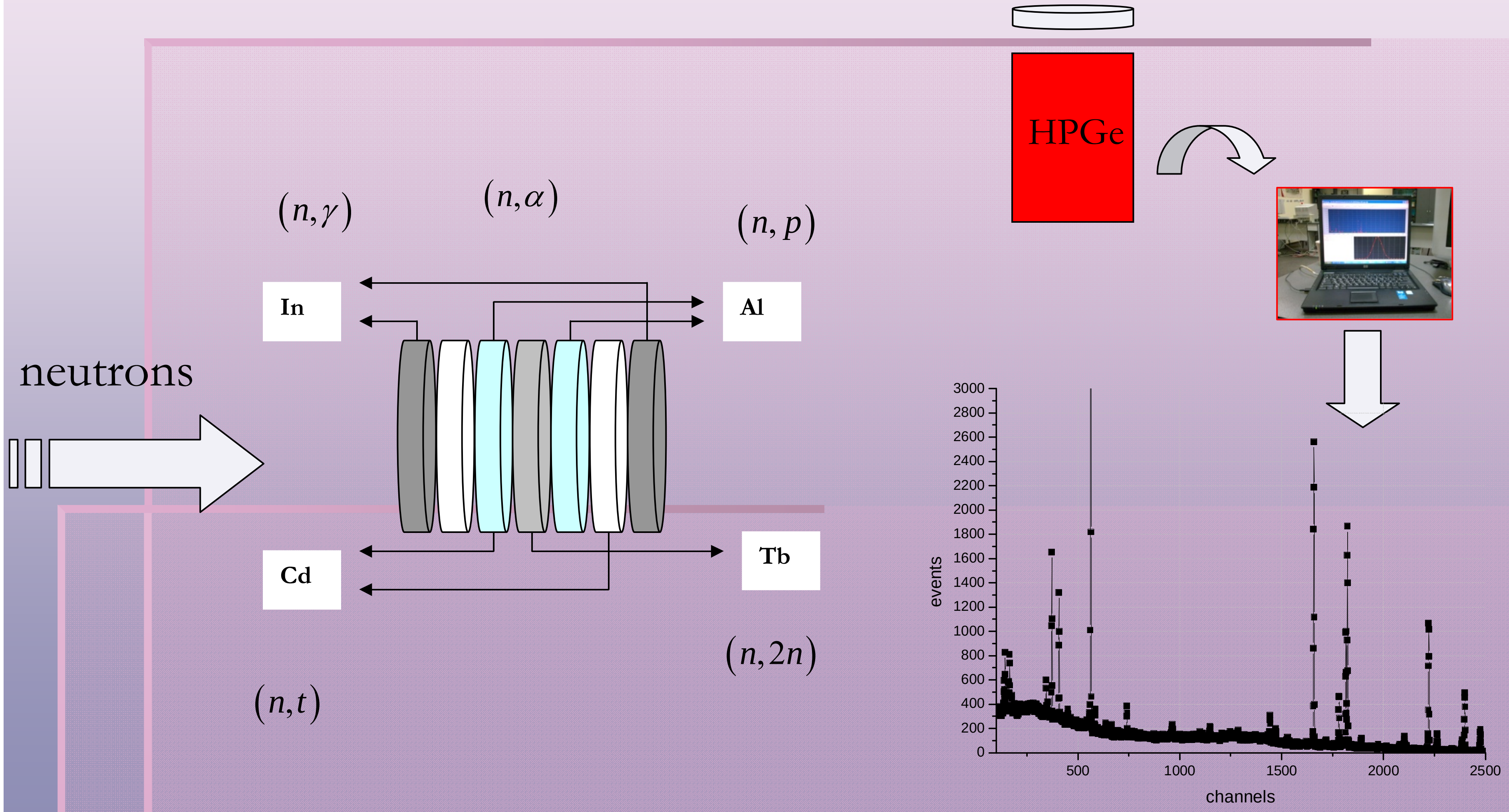
Neutron-activation method

- Neutron source is a pulse neutron generator NG-300/15
- Neutrons generated in nuclear reaction $\boxed{T(d,n)^4He}$
- Average neutron energy – E = 14.5 MeV $\longrightarrow$ $\boxed{\dfrac{{}^{90}Zr(n,2n)^{89}Zr}{{}^{93}Nb(n,2n)^{92m}Nb}}$
- Average density of neutron flux $\boxed{F = 1.6\cdot 10^{8}\ \dfrac{neutrons}{second}}$
- Monitor nuclear reaction $\boxed{{}^{27}Al(n,\alpha)^{24}Na}$ $\boxed{{}^{93}Nb(n,2n)^{92m}Nb}$
- Instrumental spectrums of nuclear reaction products were

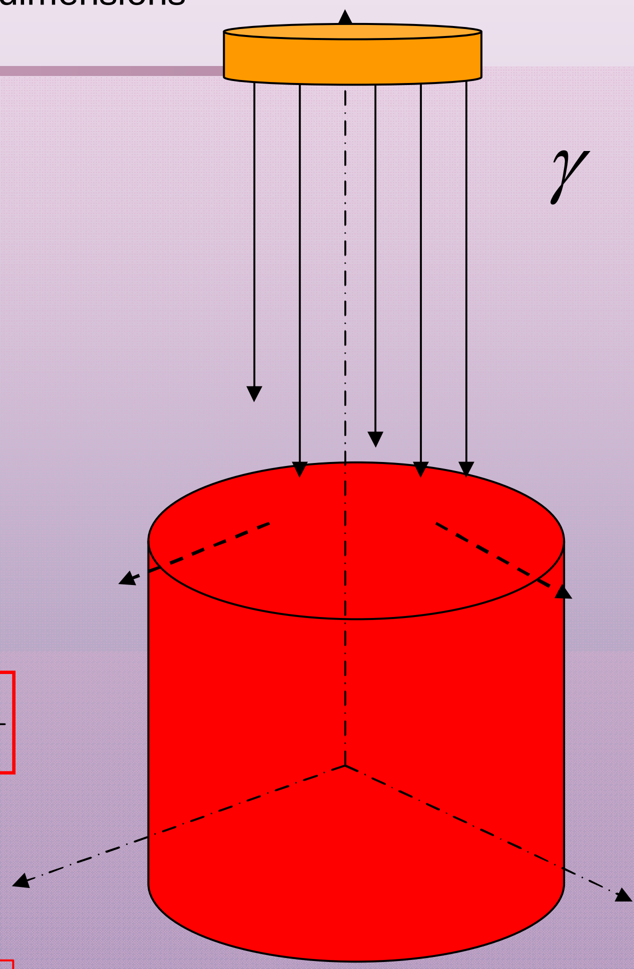
measured with HPGe (coaxial) and Ge - planar detectors

$$\boxed{\sigma_x = \frac{S_x\cdot\varepsilon_m\cdot\left(1-e^{-\lambda_m\cdot t_{irrad}}\right)\cdot e^{-\lambda_m\cdot t_{cooling\_m}}\cdot\left(1-e^{-\lambda_m\cdot t_{mes\_m}}\right)\cdot N_m\cdot n_{\gamma_m}\cdot\lambda_x}{S_m\cdot\varepsilon_x\cdot\left(1-e^{-\lambda_x\cdot t_{irrad}}\right)\cdot e^{-\lambda_x\cdot t_{cooling\_x}}\cdot\left(1-e^{-\lambda_x\cdot t_{mes\_x}}\right)\cdot N_x\cdot n_{\gamma_x}\cdot\lambda_m}\cdot\sigma_m}$$

Scheme of experiment



- Self-absorption of gamma-ray in the sample (decreasing of pecks area) → Sample's dimensions



- Coincidence summing effect (distortion of spectrum, appearance of false peaks, alterations of full-energy peaks area)

→ geometry of measurements
detectors specifications
peculiarities of decay scheme of radionuclide

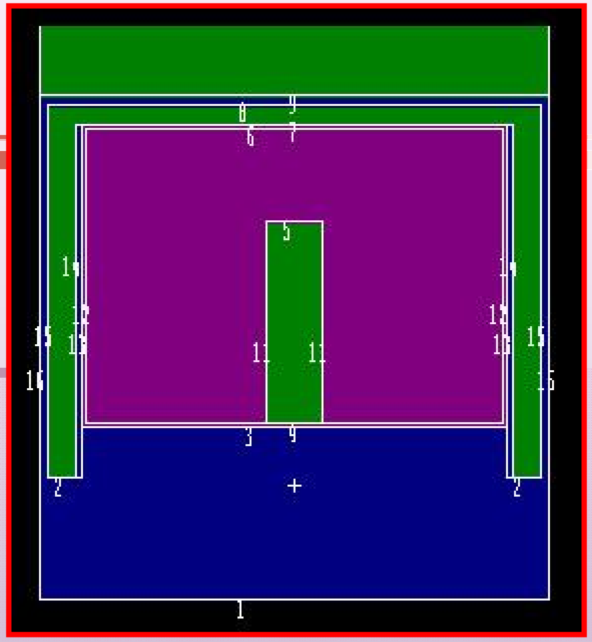
- Effect of sample positioning on the detector surface → Sample size

$$\boxed{S_{real} = S_{\det} \cdot \frac{\mu \cdot \rho \cdot d}{1 - e^{-\mu \cdot \rho \cdot d}}}$$

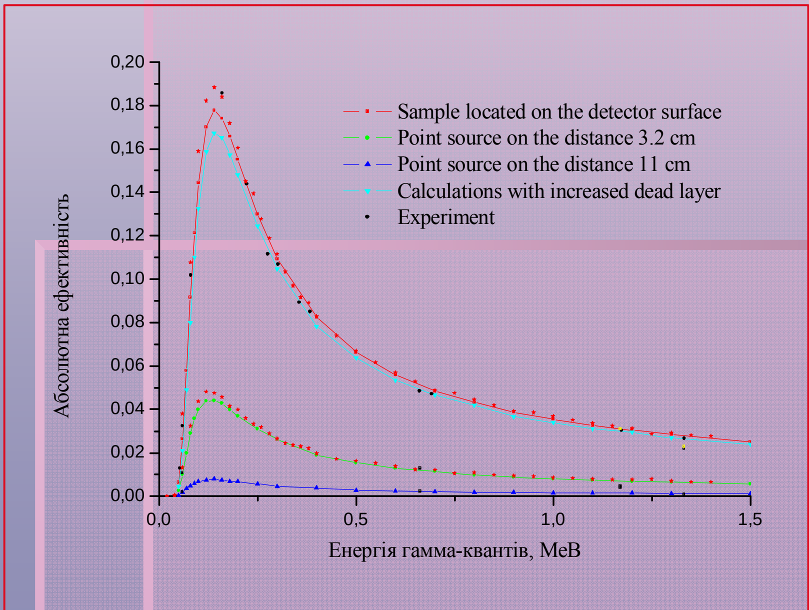
$$\boxed{\varepsilon = \varepsilon_{exp} \cdot \frac{\varepsilon_{point}}{\varepsilon_{scope}}}$$

$$\boxed{\varepsilon = \varepsilon_{exp} \cdot K_{coinsidence} \cdot K_{self-absorption}}$$

The model of detector GC2020 (CANBERRA) has been created by MCNP code



Geometry settings structure fields



$^{133}Ba \quad E_\gamma = 80.9 KeV$

$^{60}Co \quad E_\gamma = 1170 KeV$

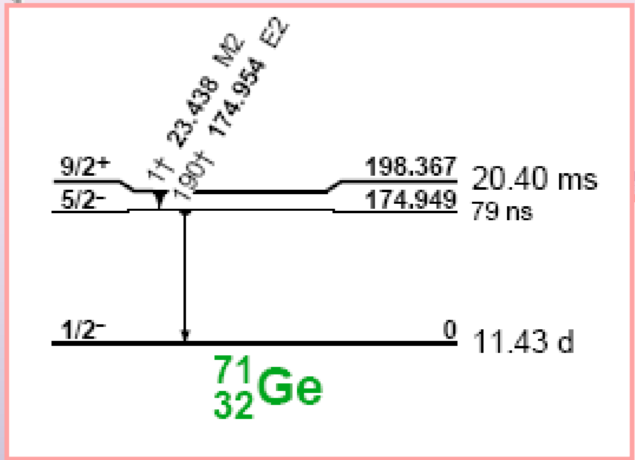
$^{60}Co \quad E_\gamma = E_\gamma = 1320 KeV$

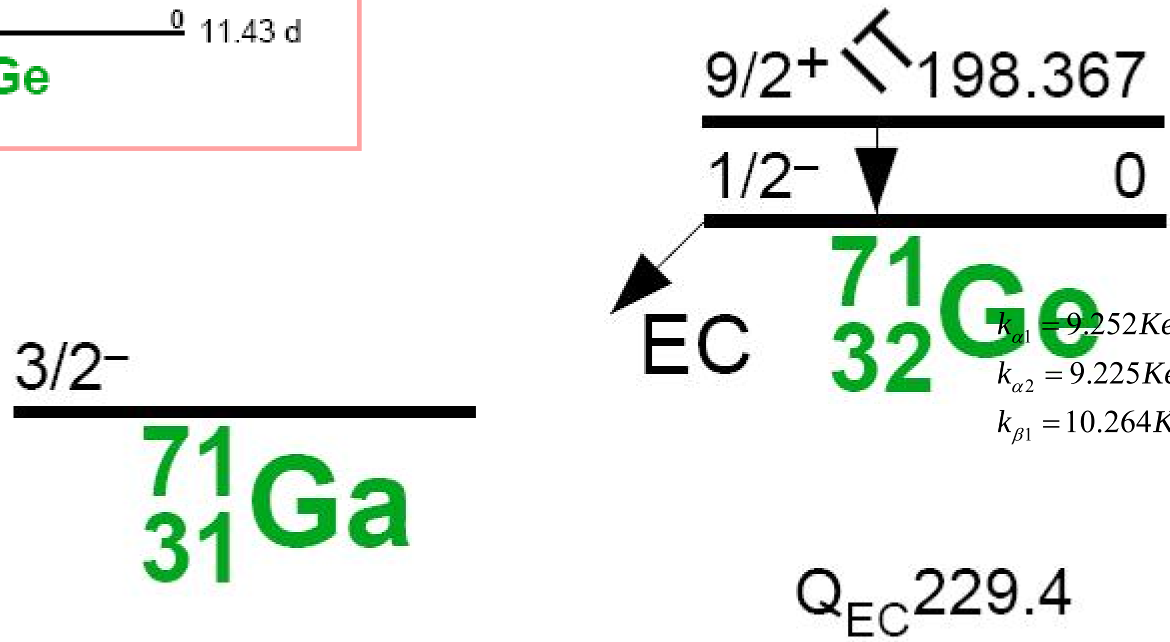
$^{137}Cs \quad E_\gamma = 662 KeV$

$^{241}Am \quad E_\gamma = 59 KeV$

- x1=5.75 cm
- x2=2.45 cm
- x3=1.1 cm
- x4=3.1 cm
- x5=0.205 cm
- x6=0.135 cm
- x7=0.135 cm
- x8=0.0003 cm
- x9=0.076 cm
- x10= 0.35 cm
- x11=7.62 cm
- x12= 0.15 cm
- x13= 0.15 cm
- x14=1.27 cm
- x15=0.15 cm
- x16=0.32 cm

Peculiarity of determination $^{72}Ge(n,2n)^{71}Ge$ cross section



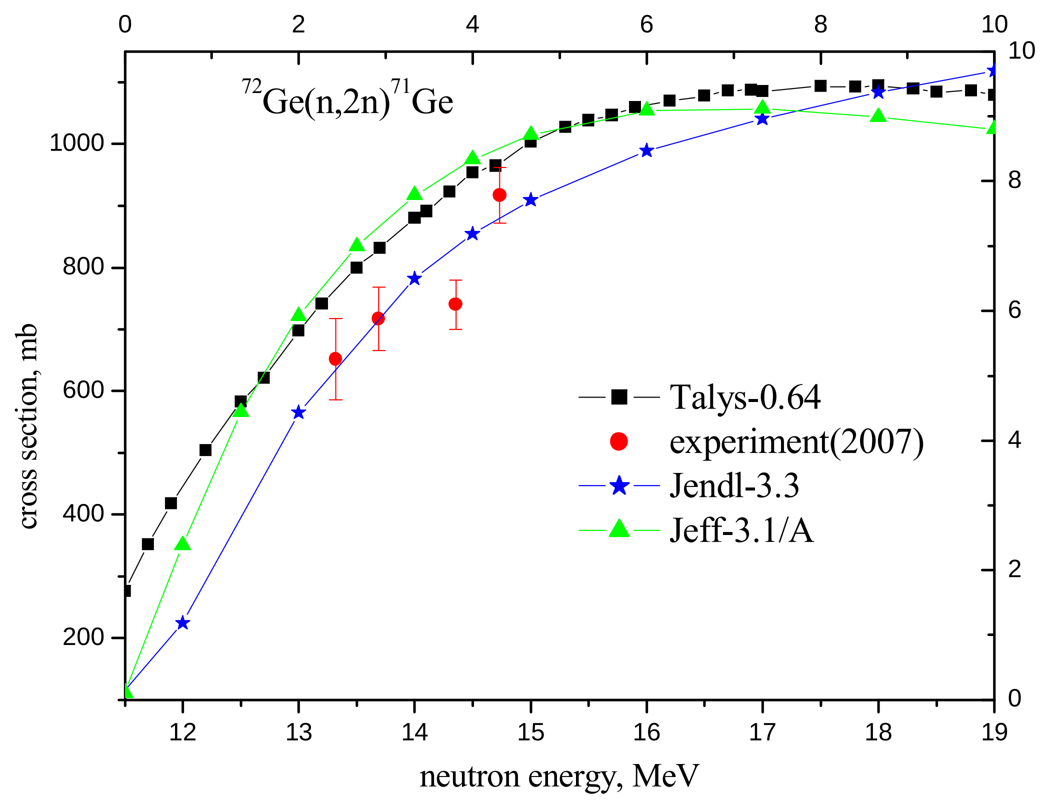


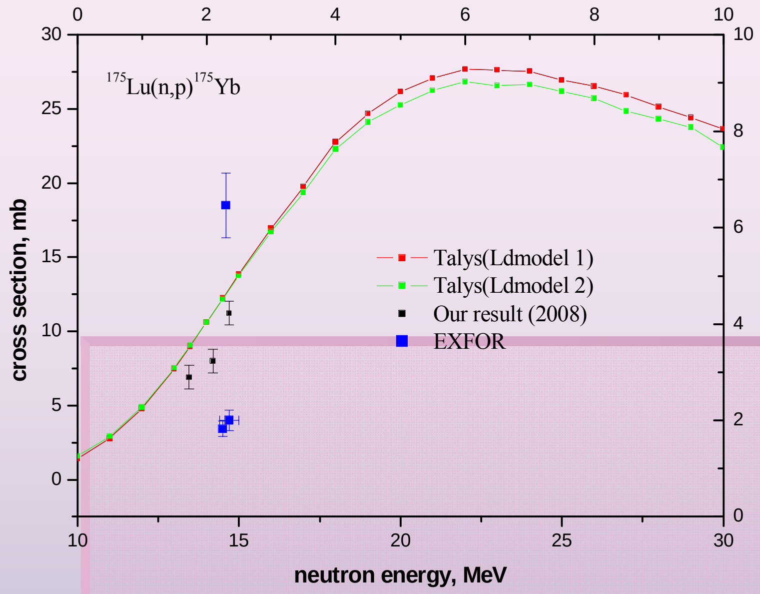
$k_{\alpha 1} = 9.252 KeV$

$k_{\alpha 2} = 9.225 KeV$

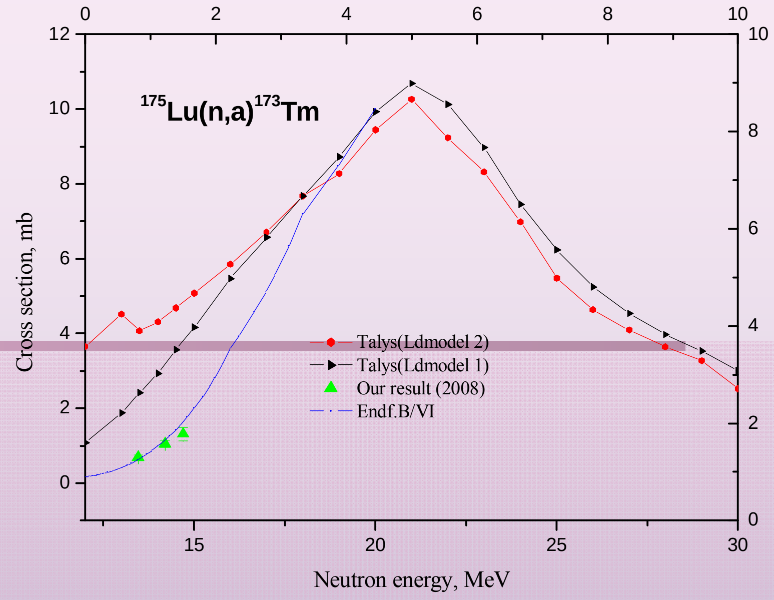
$k_{\beta 1} = 10.264 KeV$

Peculiarity of determination $^{72}Ge(n,2n)^{71}Ge$ cross section

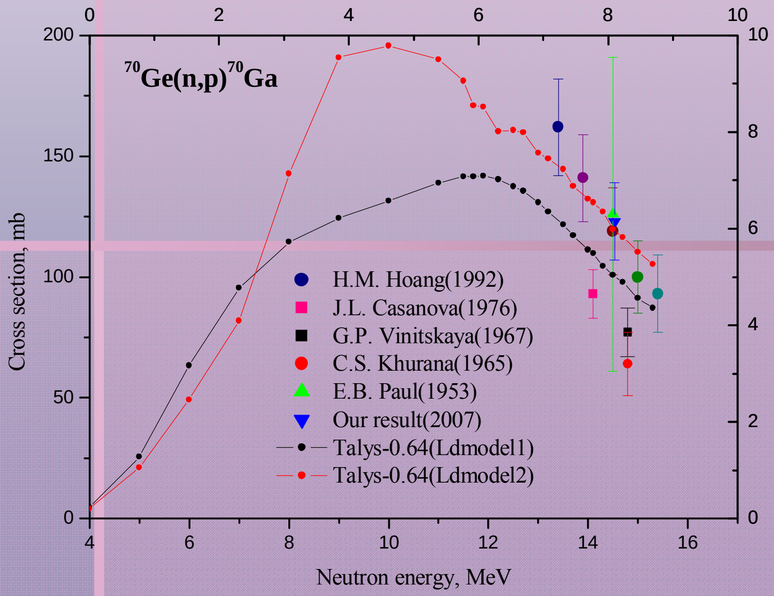




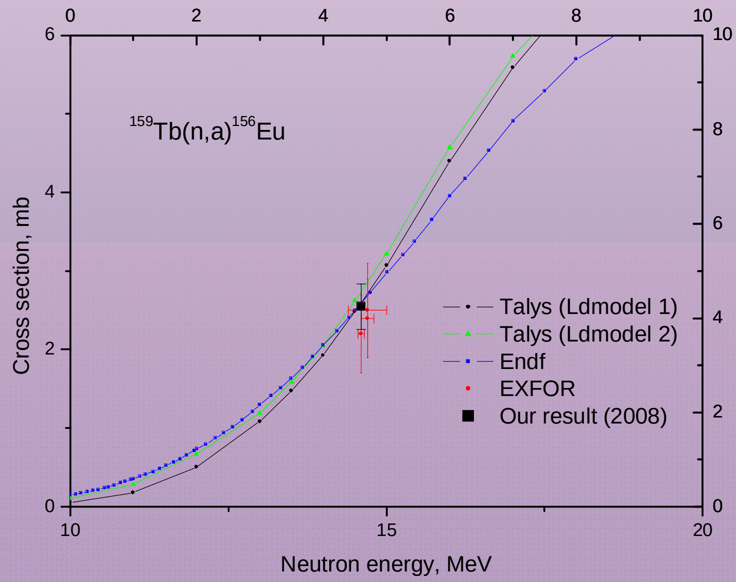
^{175}Lu(n,p)^{175}Yb
Talys(Ldmodel 1)
Talys(Ldmodel 2)
Our result (2008)
EXFOR
cross section, mb
neutron energy, MeV



^{175}Lu(n,a)^{173}Tm
Talys(Ldmodel 2)
Talys(Ldmodel 1)
Our result (2008)
Endf.B/VI
Cross section, mb
Neutron energy, MeV



^{70}Ge(n,p)^{70}Ga
H.M. Hoang(1992)
J.L. Casanova(1976)
G.P. Vinitskaya(1967)
C.S. Khurana(1965)
E.B. Paul(1953)
Our result(2007)
Talys-0.64(Ldmodel1)
Talys-0.64(Ldmodel2)
Cross section, mb
Neutron energy, MeV



^{159}Tb(n,a)^{156}Eu
Talys (Ldmodel 1)
Talys (Ldmodel 2)
Endf
EXFOR
Our result (2008)
Cross section, mb
Neutron energy, MeV

Nuclear reaction	Cross section, mb	Neutron energy, MeV	EXFOR
$^{70}Ge(n, p)^{70}Ga$	123(12)	14,53	119(8)
$^{74}Ge(n, a)^{71m}Zn$	3,4(0,6)	14,53	3,4(0,4)
$^{72}Ge(n, 2n)^{71}Ge$	653(66)	13,36	–
$^{72}Ge(n, 2n)^{71}Ge$	717(51)	13,69	–
$^{72}Ge(n, 2n)^{71}Ge$	740(45)	14,36	–
$^{72}Ge(n, 2n)^{71}Ge$	917(77)	14,74	–
$^{76}Ge(n, 2n)^{75(m+g)}Ge$	914(73)	14,53	1160(130)
$^{76}Ge(n, 2n)^{75m}Ge$	700(50)	14,53	800(56)
$^{70}Ge(n, 2n)^{69}Ge$	470(80)	14,53	490(80)

Nuclear reaction	Half-life	Neutron energy, MeV	Cross section, mb	EXFOR
$^{175}Lu(n,2n)^{174m}Lu$	142 days	13.47	480(63)	–
		14.2	382(59)	515(36)
		14.6	567(60)	627(52)
$^{175}Lu(n,2n)^{174g}Lu$	3.31 years	13.47	1896(250)	1890(124)
		14.2	1473(219)	1670(159)
		14.6	1860(190)	1900(162)
$^{175}Lu(n,p)^{176}Yb$	4.19 days	13.47	10.7(0.7)	–
		14.2	9.8(0.7)	–
		14.6	13.2(0.9)	18.5(2.2) 3.4(0.5)
$^{175}Lu(n,a)^{172}Tm$	63.6 hour	13.47	0.7(0.1)	–
		14.2	1(0.03)	–
		14.6	1.5(0.2)	–
$^{176}Lu(n,a)^{173}Tm$	8.24 hour	14.6	1.63(0.34)	2.3(0.6)

Nuclear reaction	Half-live	Cross section, mb	EXFOR
$^{159}Tb(n,p)^{159}Gd$	18,48 hour	4.8(0.5)	6.6(0.7)
$^{159}Tb(n,a)^{156}Eu$	15,19 days	2.2(0.3)	2.2(0.5)
$^{159}Tb(n,2n)^{158}Tb$	180 years	1913(60)	1909(82)

Conclusions

- **Four cross sections for** $^{72}Ge(n,2n)^{71}Ge$ **nuclear reactions and three cross sections for** $^{175}Lu(n,a)^{172}Tm$ **have been measured experimentally at first time**
- **Cross sections for** $^{176}Lu(n,a)^{173}Tm$ **and** $^{175}Lu(n,p)^{176}Yb$ **nuclear reactions have been improved**
- **Effectiveness and correctness of neutron-activation method were confirmed by good agreement of obtained results with results of other research groups**
- **These results can be used to update nuclear databases**
- **Obtained results can be considered as important in the process of nuclear data estimation**


Thanks for your attention !!!!
Welcome to Kiev !!!