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

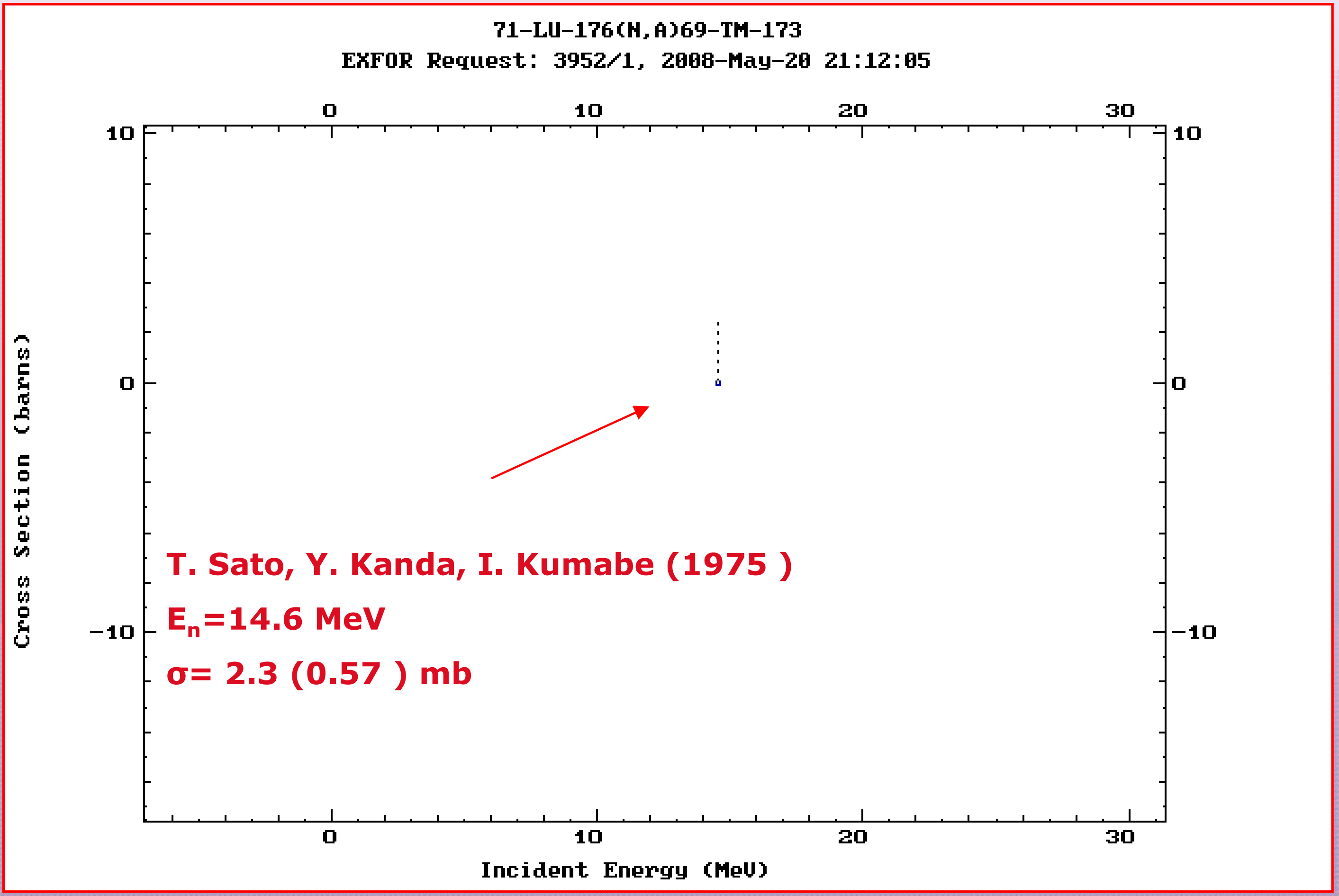
- Incompleteness of EXFOR database

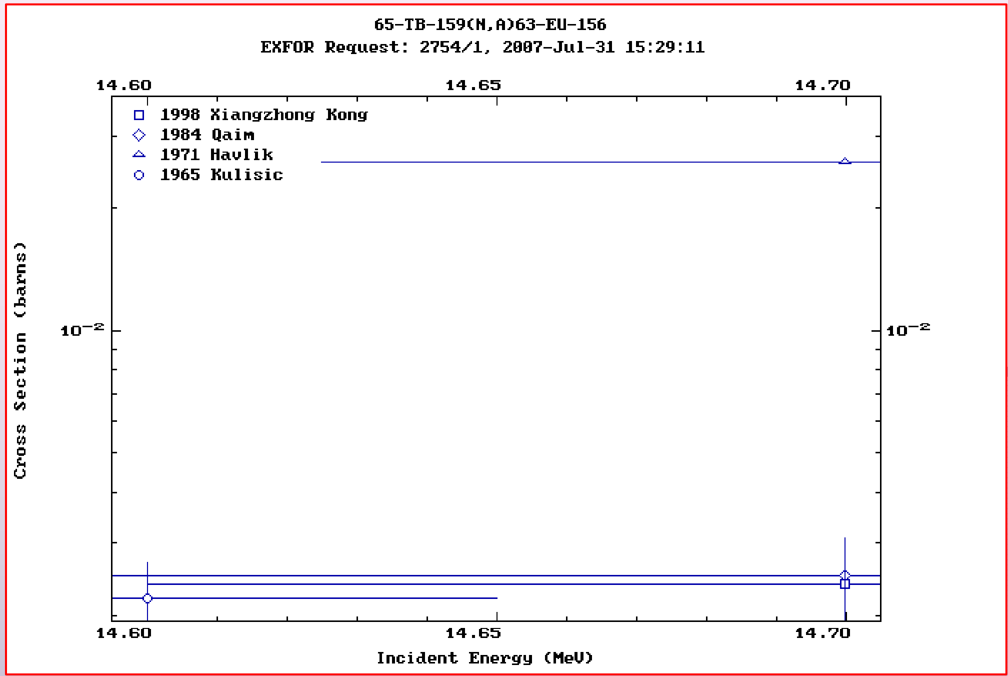
NO DATA FOUND

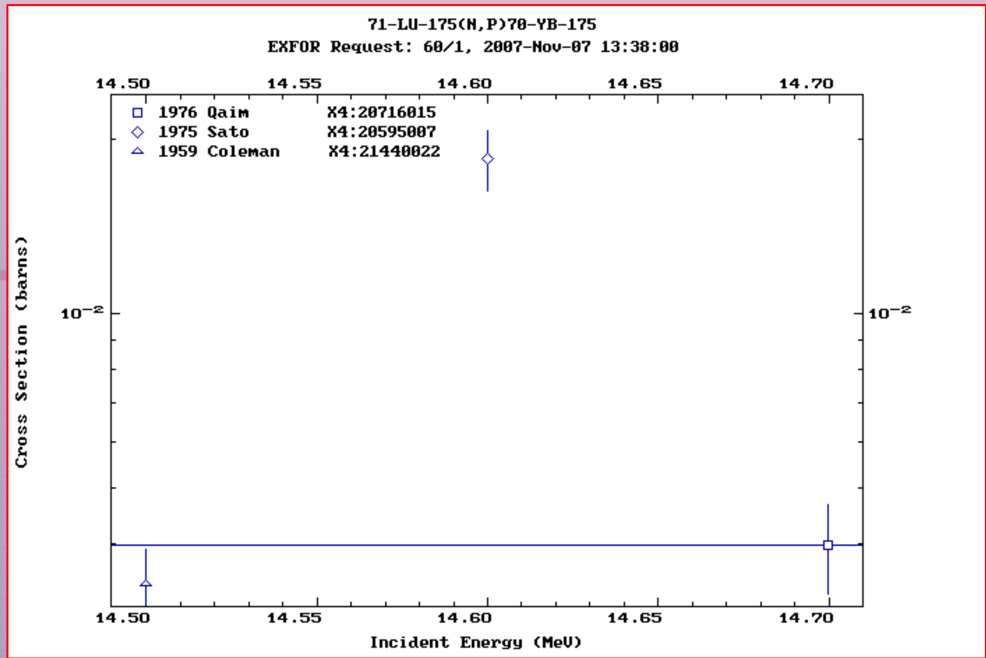
$^{72}Ge(n,2n)^{71}Ge$ $^{175}Lu(n,\alpha)^{172}Tm$ $^{176}Lu(n,\alpha)^{173}Tm$

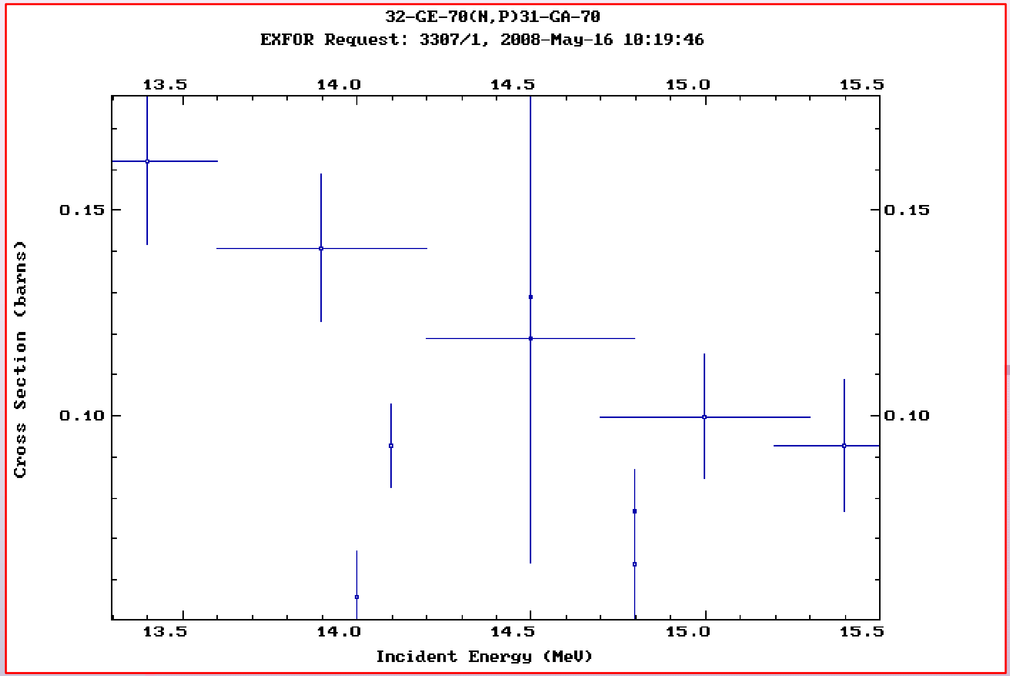
- Discrepancy in cross section values

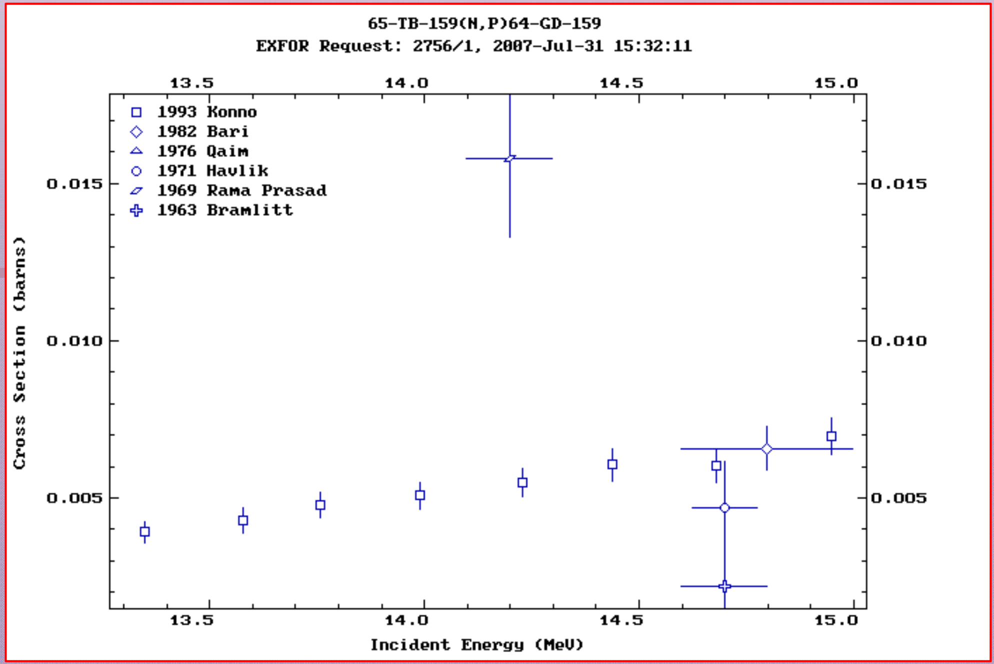
Reasons why cross sections are necessary




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)
13.5
14.0
14.5
15.0
15.5
0.15
0.10


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)
13.5
14.0
14.5
15.0
0.015
0.010
0.005

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**

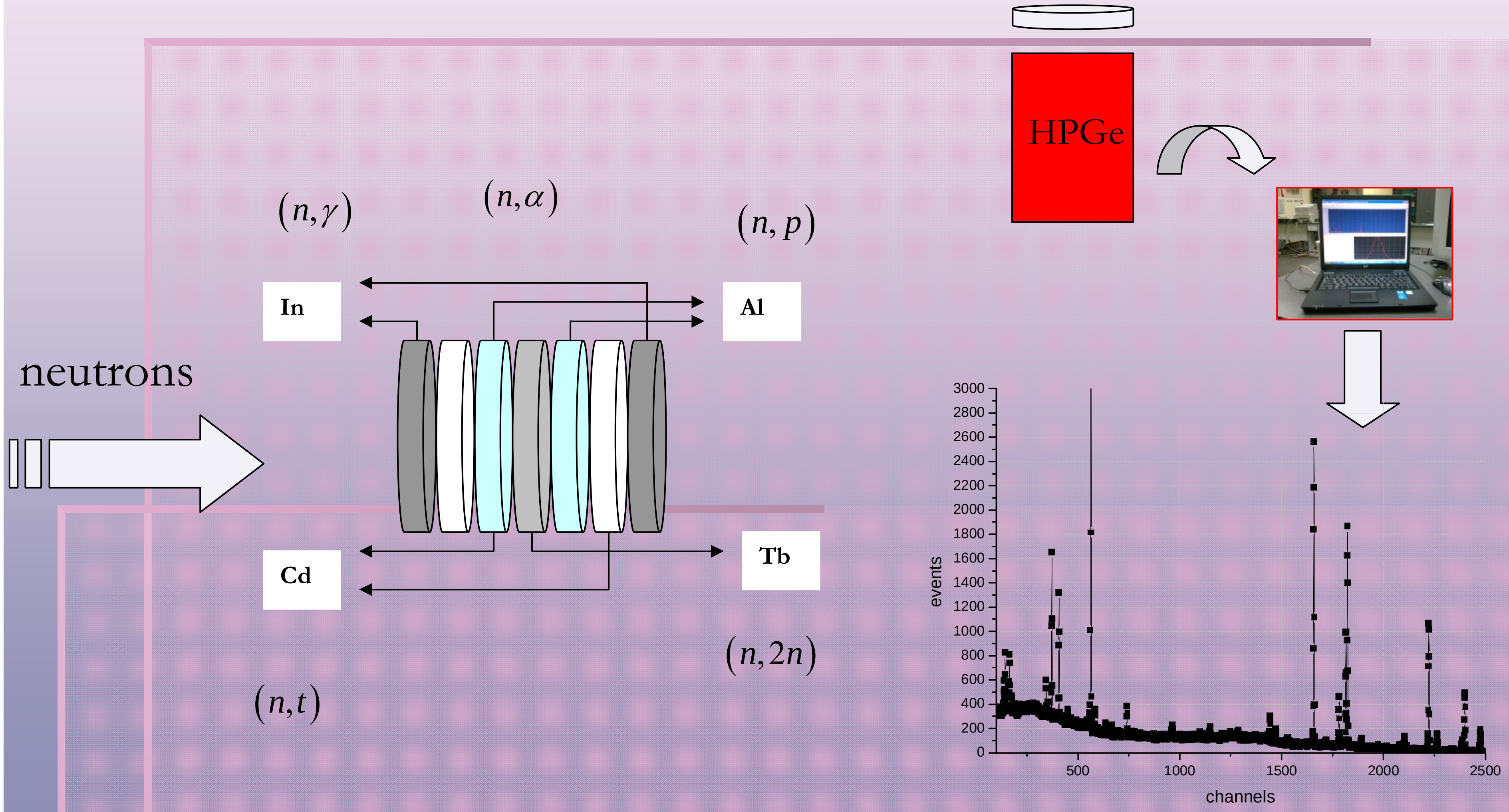
R. Forrest EURATOM/UKAEA Fusion Association, Culham Science Center,
Abingto,Oxon OX14 3DB, UK
Fusion Engineering and Design 81 (2006) 2157-2174
"Data requirements for neutron activation" Part I: Nuclear data
"Data requirements for neutron activation" Part II: Decay data

Neutron-activation method

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

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

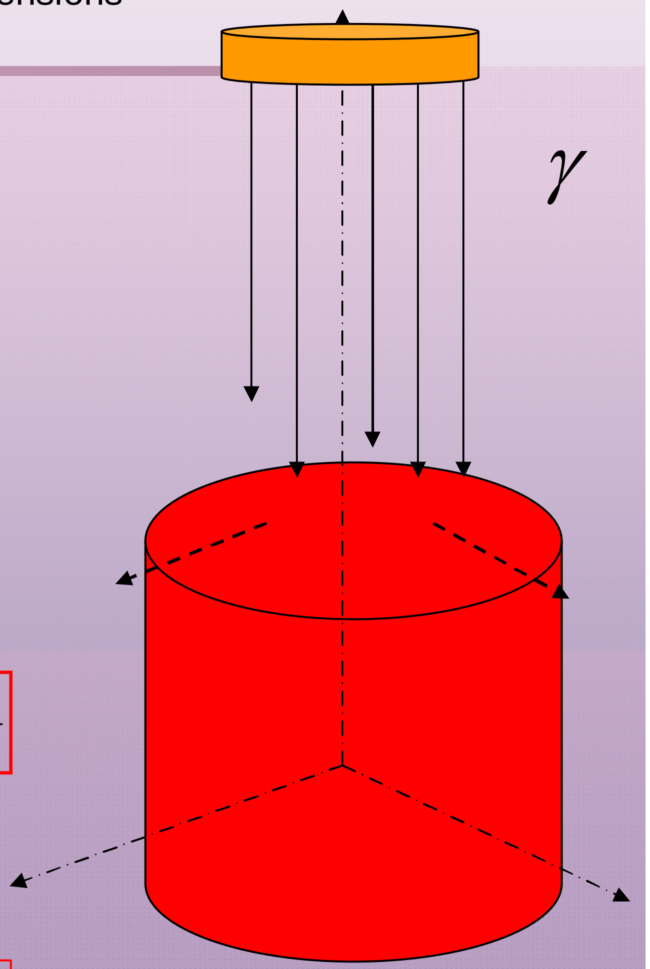
Scheme of experiment



- 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

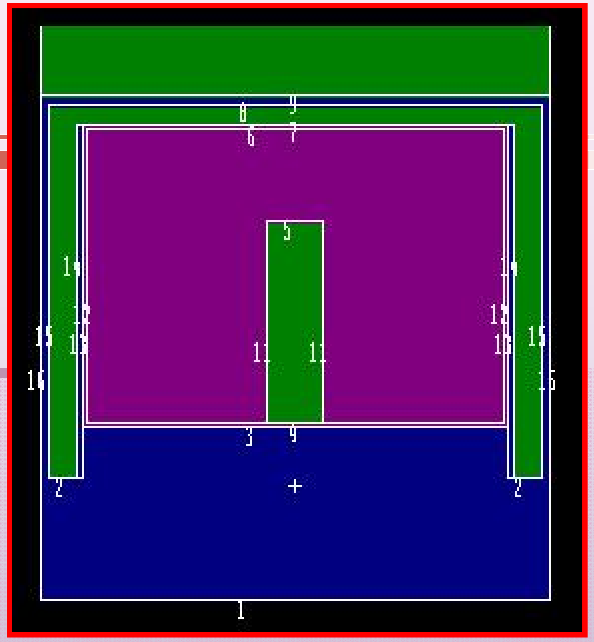


$$S_{real} = S_{\det} \cdot \frac{\mu \cdot \rho \cdot d}{1 - e^{-\mu \cdot \rho \cdot d}}$$

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

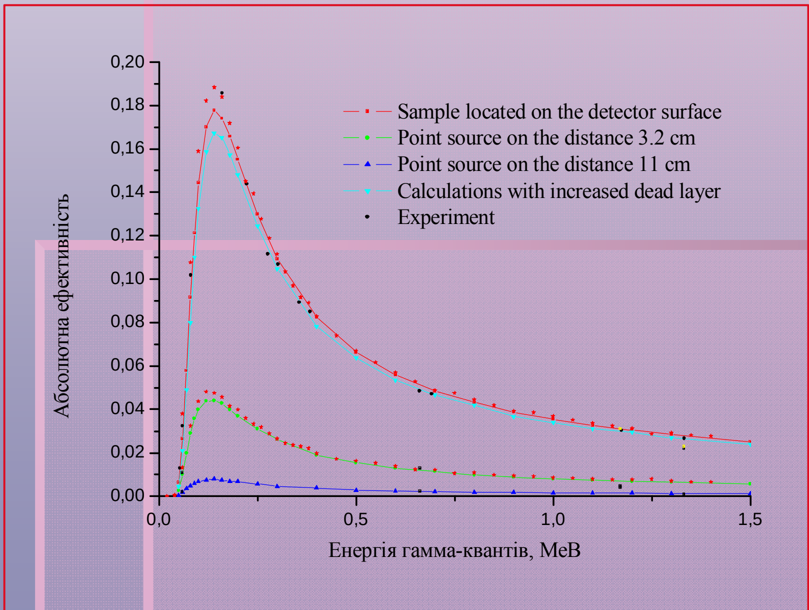
$$\varepsilon = \varepsilon_{exp} \cdot K_{coinsidence} \cdot K_{self-absorption}$$

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



Geometry settings structure fields

- 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



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

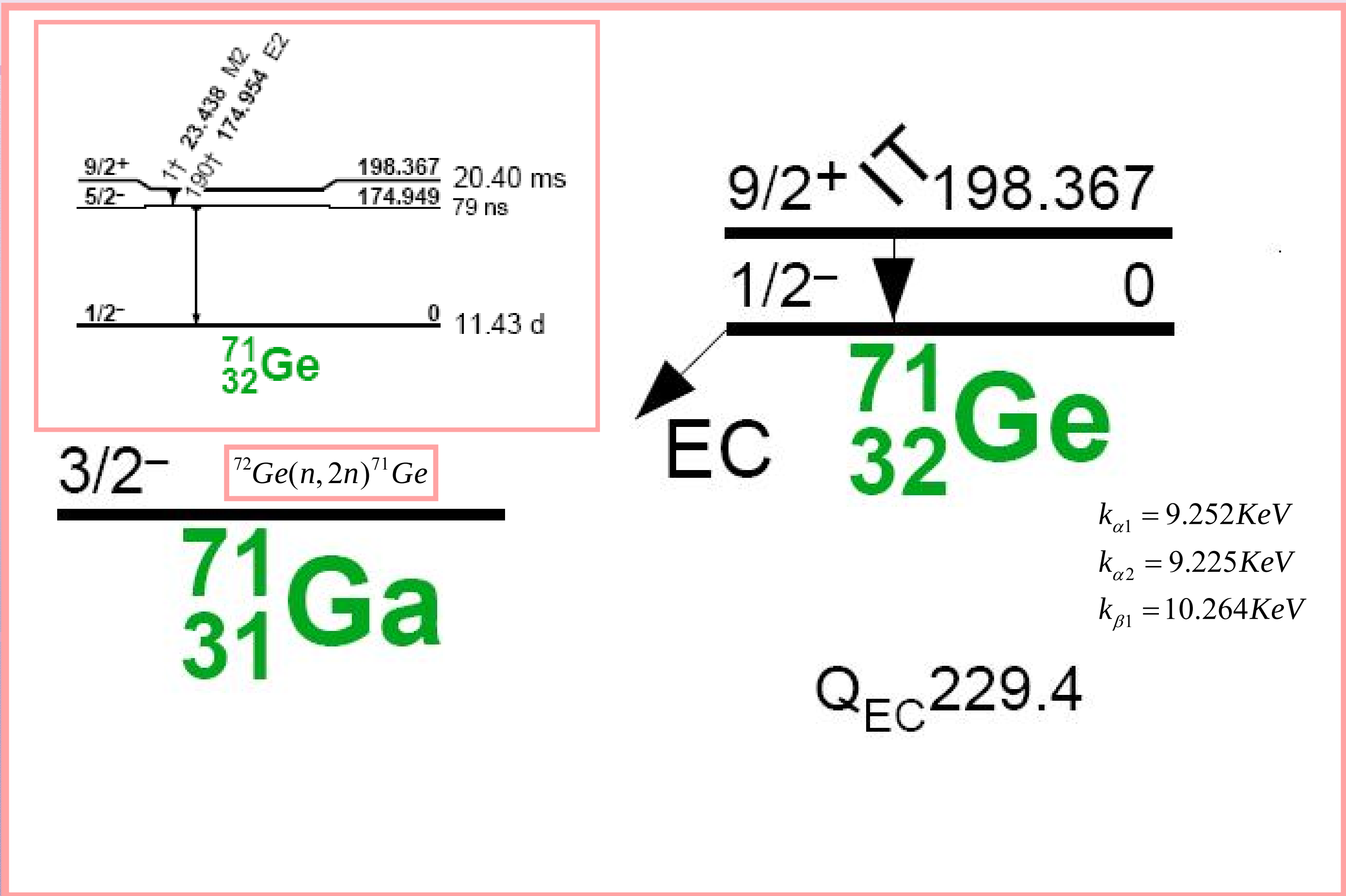
$^{60}Co \quad E_{\gamma} = 1170 KeV$

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

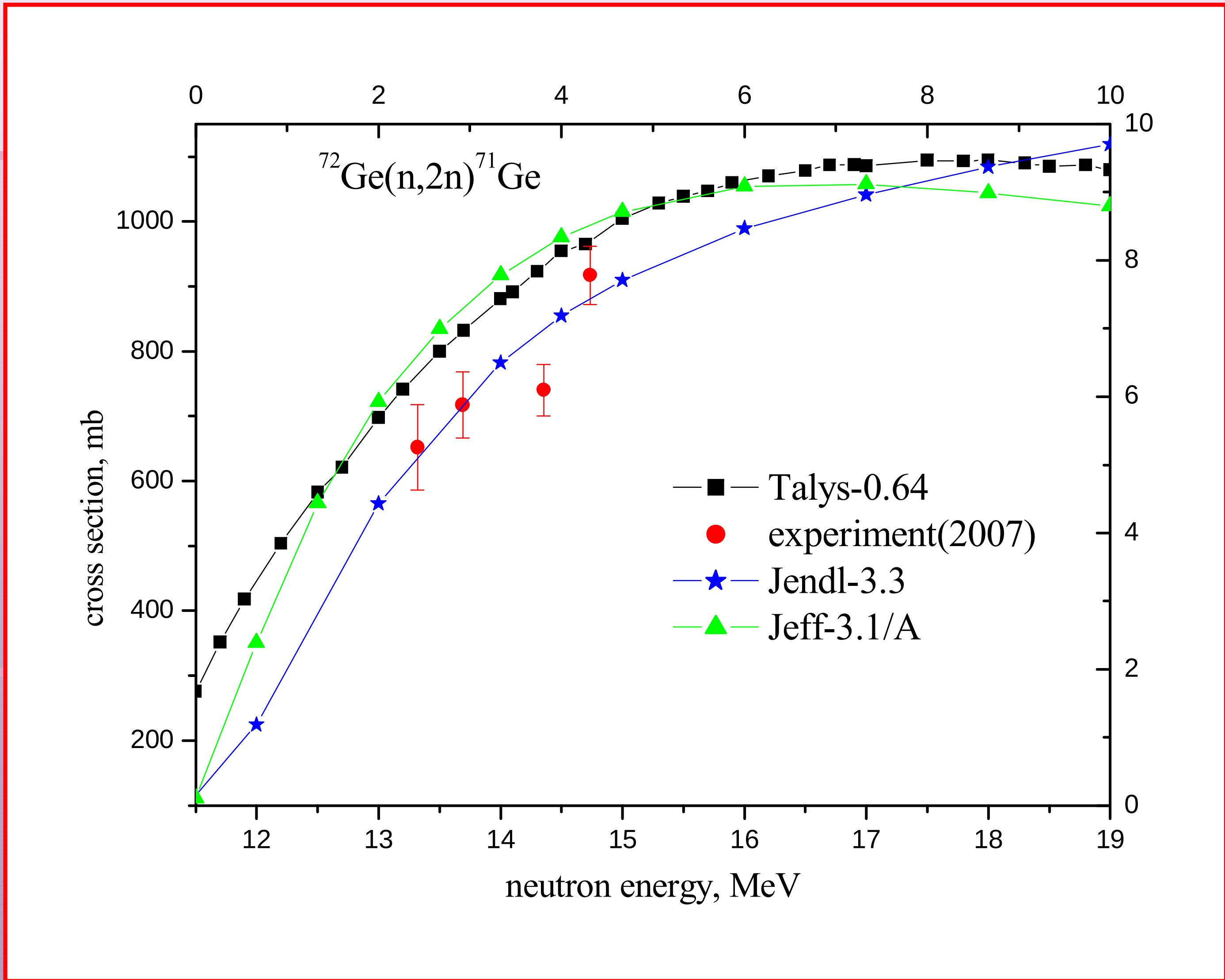
$^{137}Cs \quad E_{\gamma} = 662 KeV$

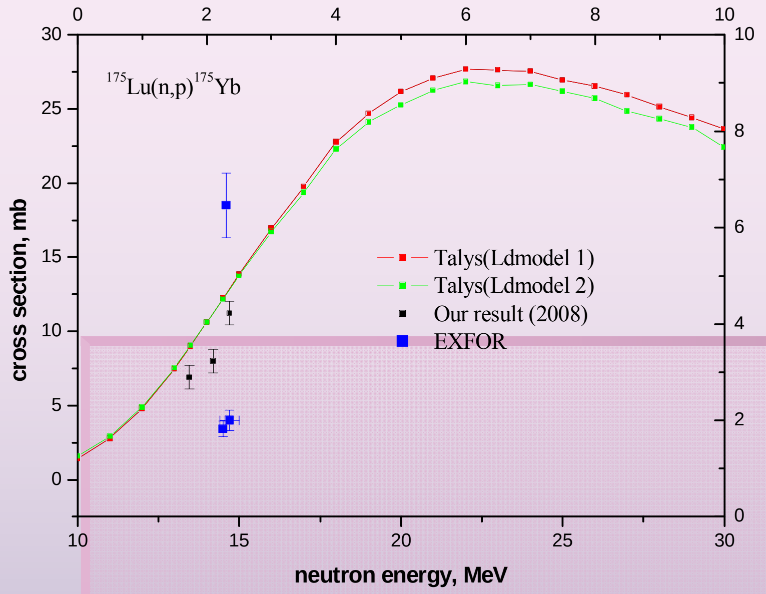
$^{241}Am \quad E_{\gamma} = 59 KeV$

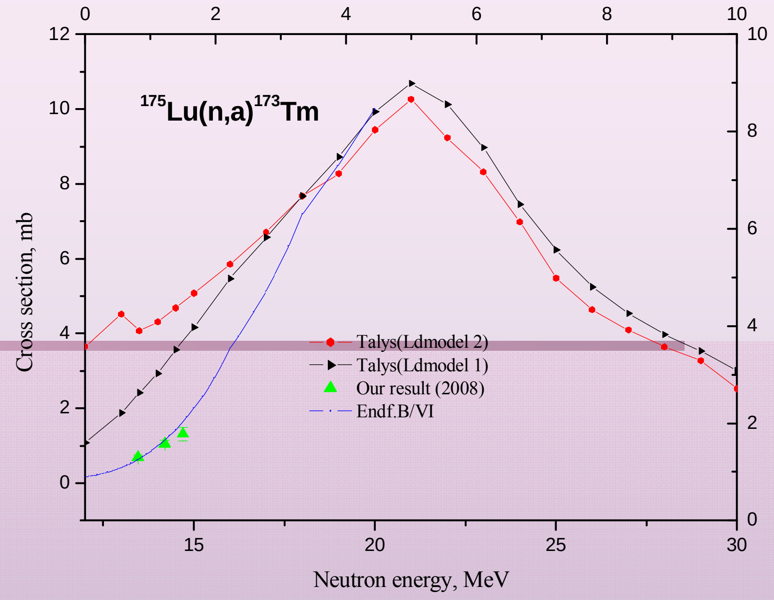
Peculiarity of determination $^{72}Ge(n,2n)^{71}Ge$ cross section

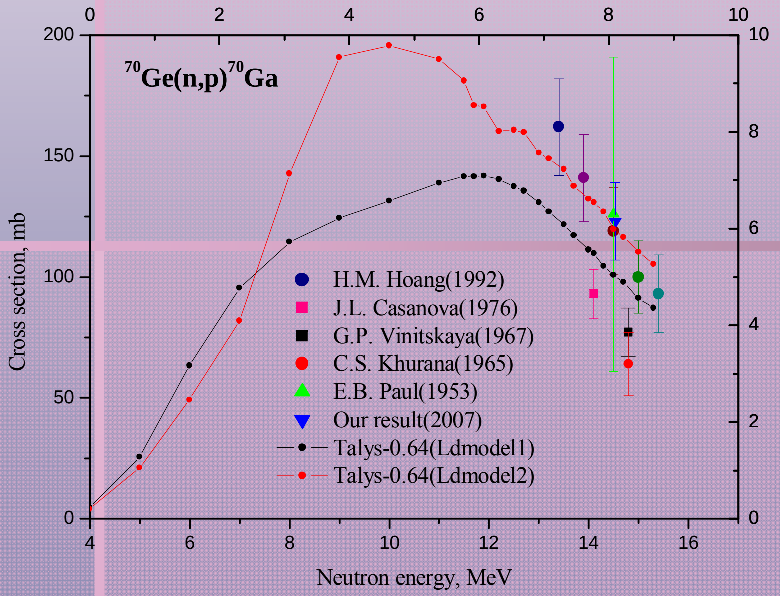


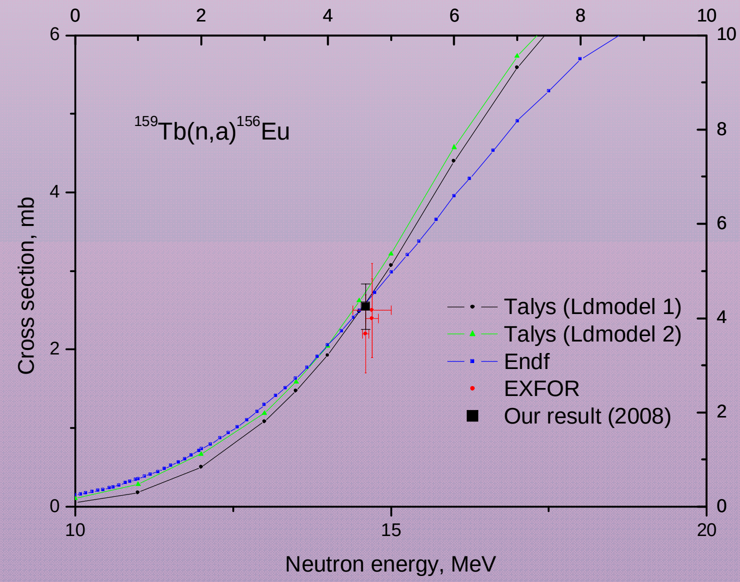
Peculiarity of determination $^{72}Ge(n,2n)^{71}Ge$ cross section











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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 !!!