Group 100/6

Low Energy Nuclear Physics

Group Members

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6. **Hakobyan Marieta**

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1. GEANT, TALYS, EMPIRE, SRIM, TRIM , SSSM

2. Excitation Functions of Protons Induced Reactions on Cyclotron C18

3. Investigation of Possibility Obtaining Neutron Beams on C18

TENDL2012

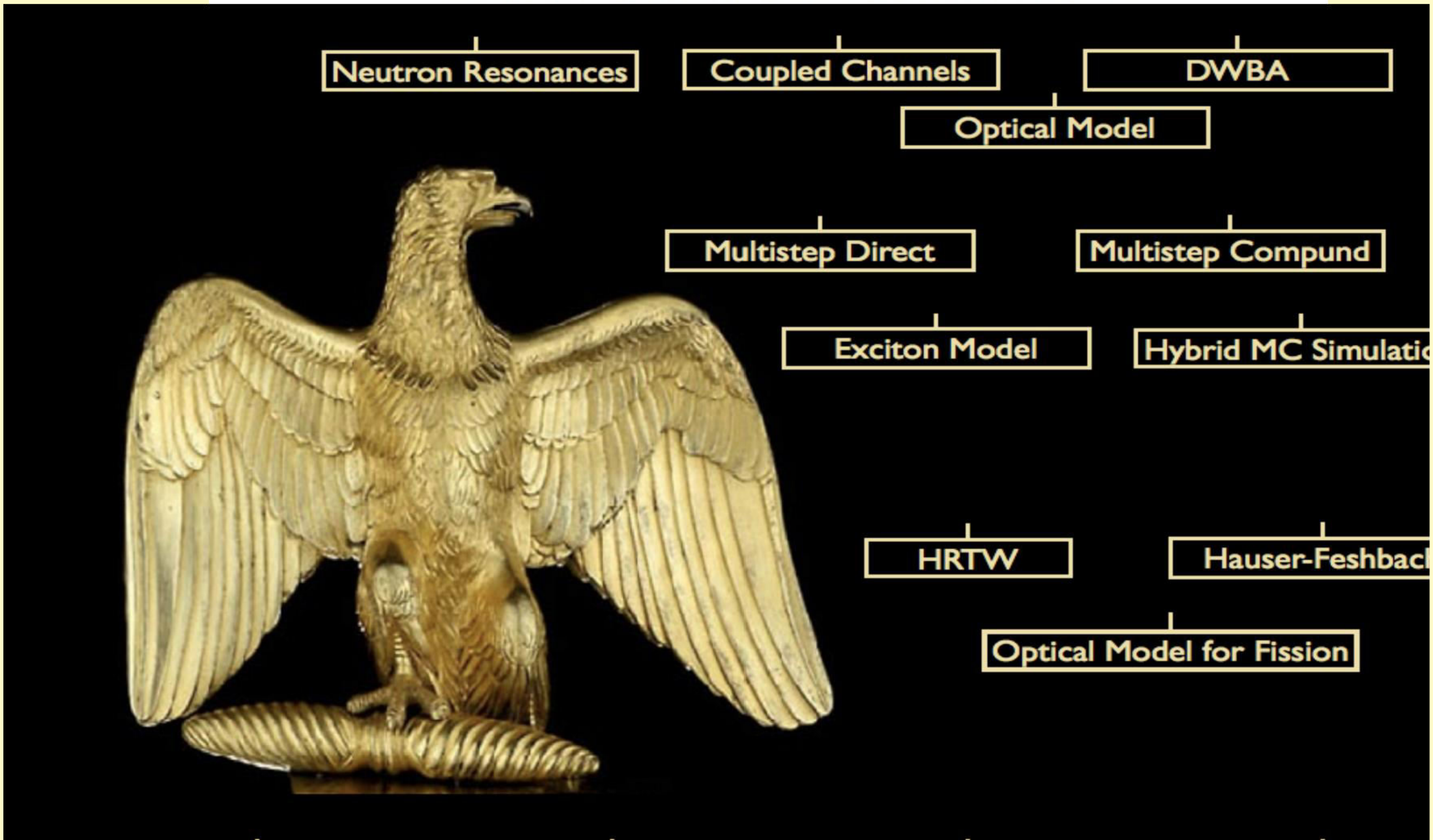
TALYS-based
Evaluated Nuclear
Data
Library

***TENDL** is a nuclear data library which provides the output of the TALYS nuclear model code system for direct use in both basic physics and applications.*

***TENDL** contains evaluations for seven types of incident particles, for all isotopes living longer than 1 second (about 2400 isotopes), up to 200 MeV.*

EMPIRE-3.1 (Rivoli)

Nuclear Reaction Model Code



SRIM

The Stopping and Range of Ions in Matter

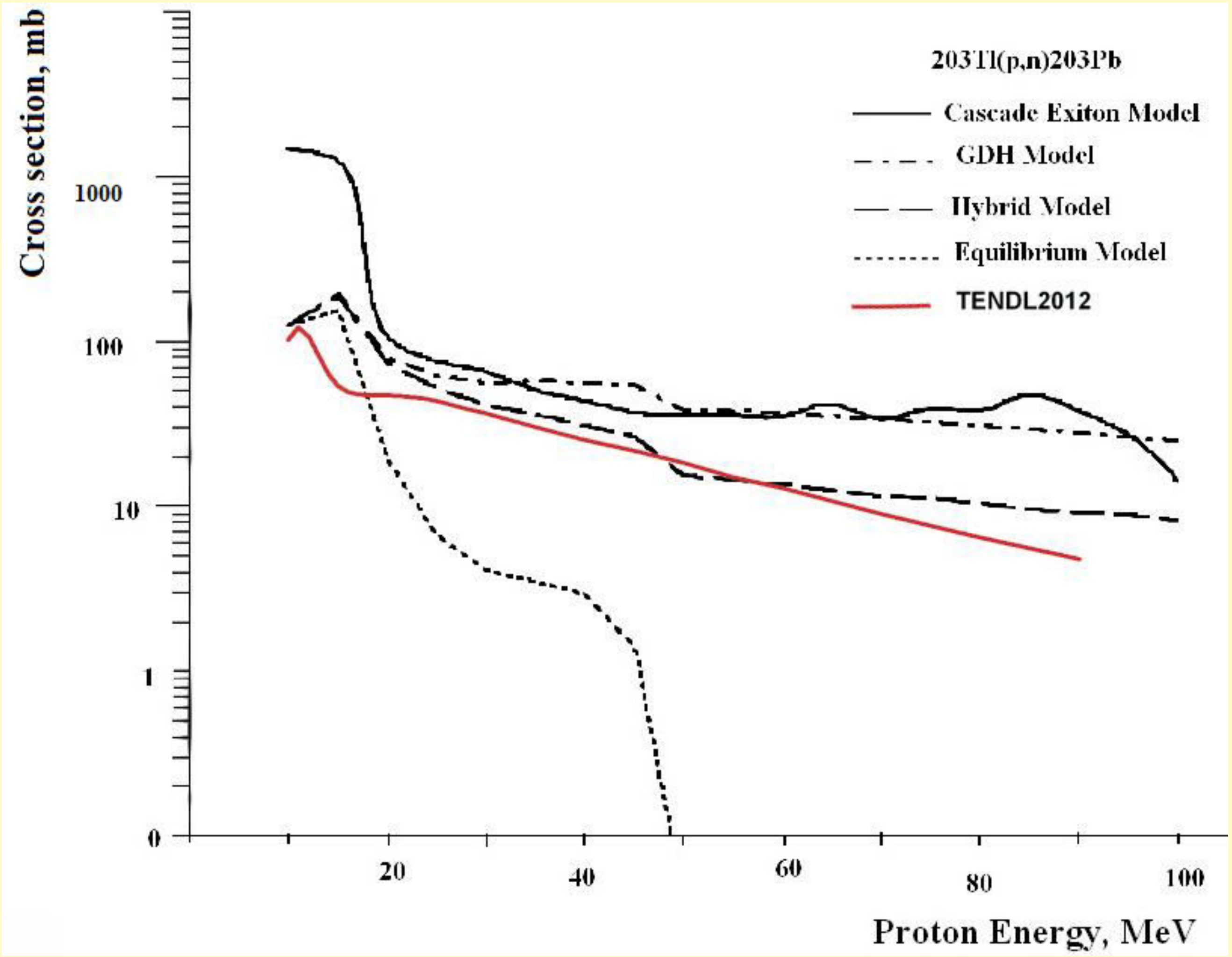
Activation Technique in Investigation of Excitation Functions of Protons Induced Reactions on Cyclotron C18

Motivation

Nuclear data evaluation is generally carried out on the basis of experimental data and theoretical model calculations RIPL (Reference Input Parameter Library). It is both practically and economically impossible to measure necessary cross-sections for all the isotopes in the periodic table for a wide range of energies. Therefore, nuclear reaction model calculations play an important role in the nuclear data evaluation.

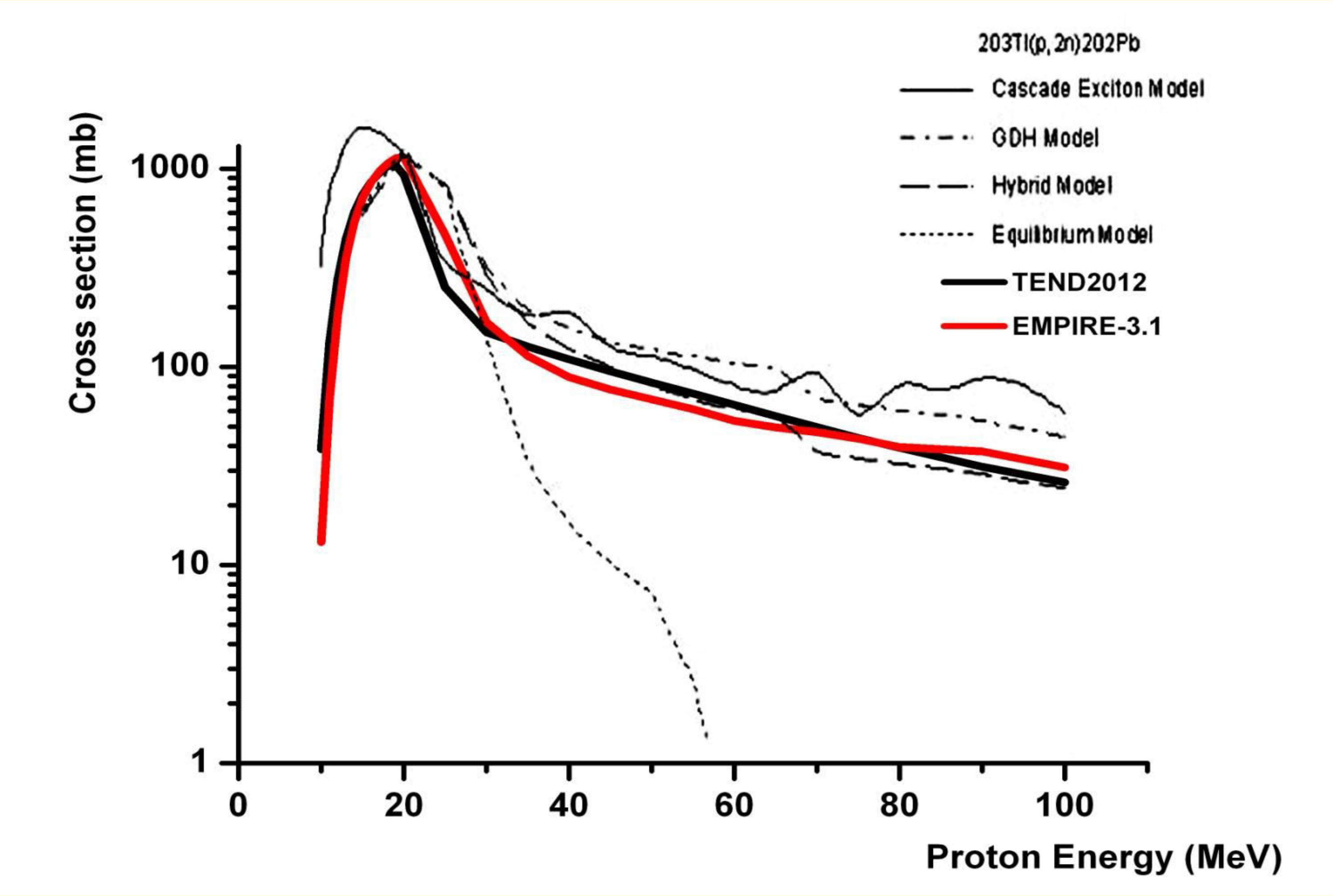
Surveying the information of excitation functions and yields of the reactions has shown that:

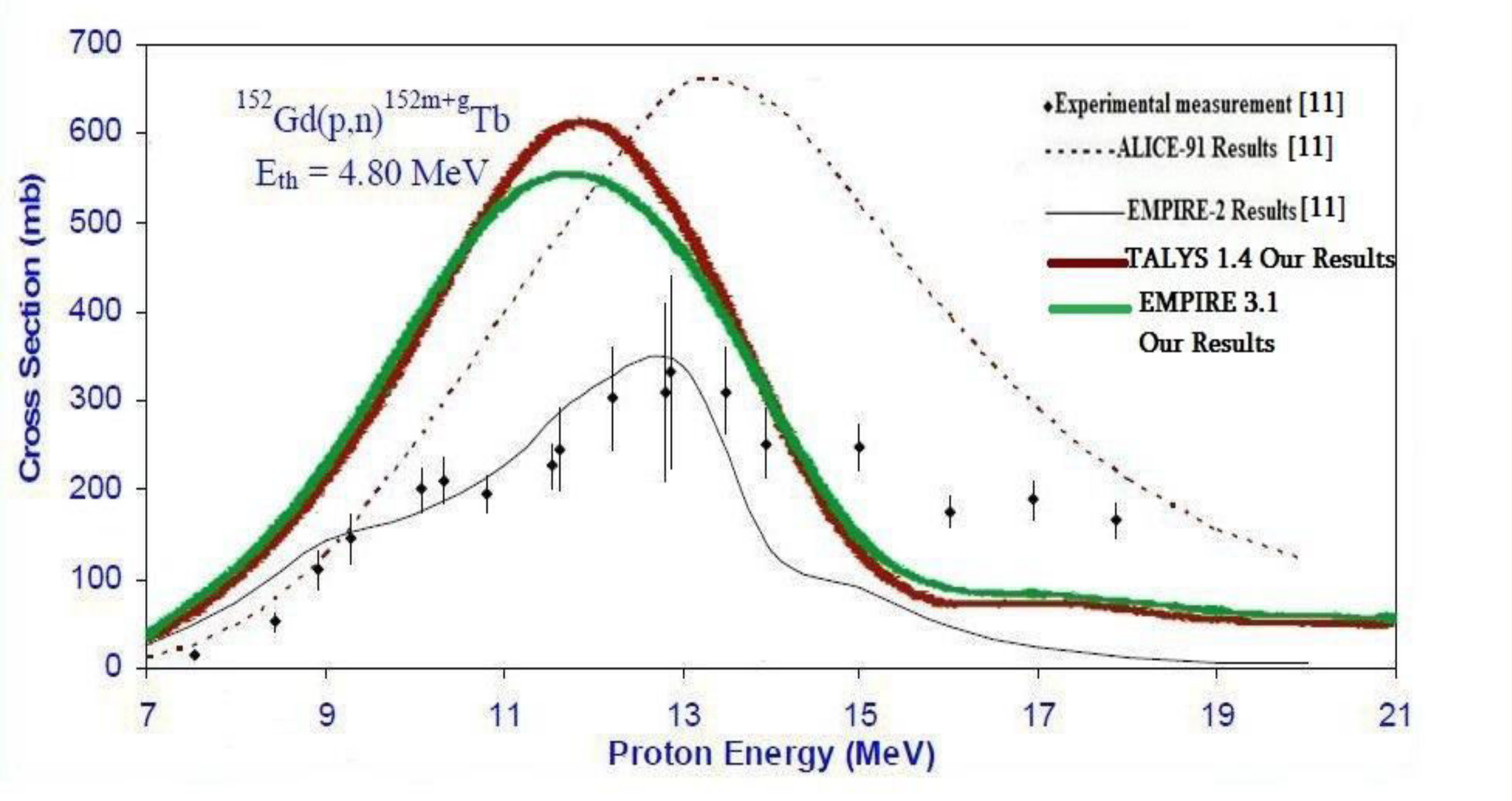
- **published cross sections have relatively high errors , the excitation functions were measured in not enough detailed;**
- **the reported cross sections from different groups often showed unacceptable deviations both in the values of the cross sections and in their energy scales;**
- **reported calculated and/or measured thick target integral yields have significant differences.**



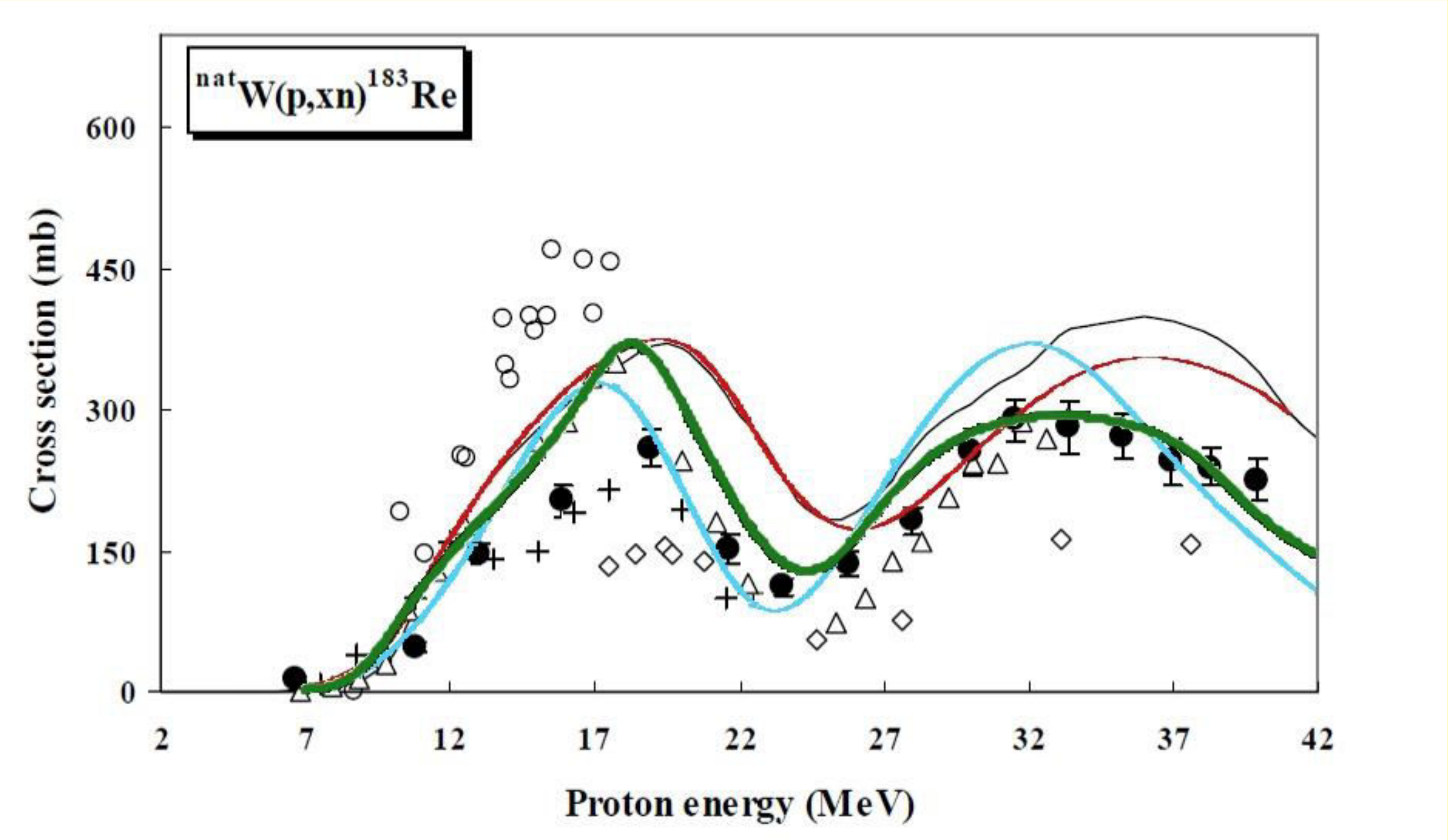
A. Kaplan, A. Ydin, E. Tel and A. Sarer, "Equilibrium and pre-equilibrium emissionsin proton-induced reactions on $^{203;205}$*Tl*", Pramana-J. Phys., Vol. 72, No. 2, (2009)

$^{203}Tl(p,2n)^{202}Pb$





M.B. Challan, G.S. Moawad, M.A. Abou-Zeid, and M.N.H. Comsan, Excitation functions of radionuclides produced by proton induced reactions ongadolinium targets, 6th Conference on Nuclear and Particle Physics17-21 Luxor, Egypt Nov. 2007

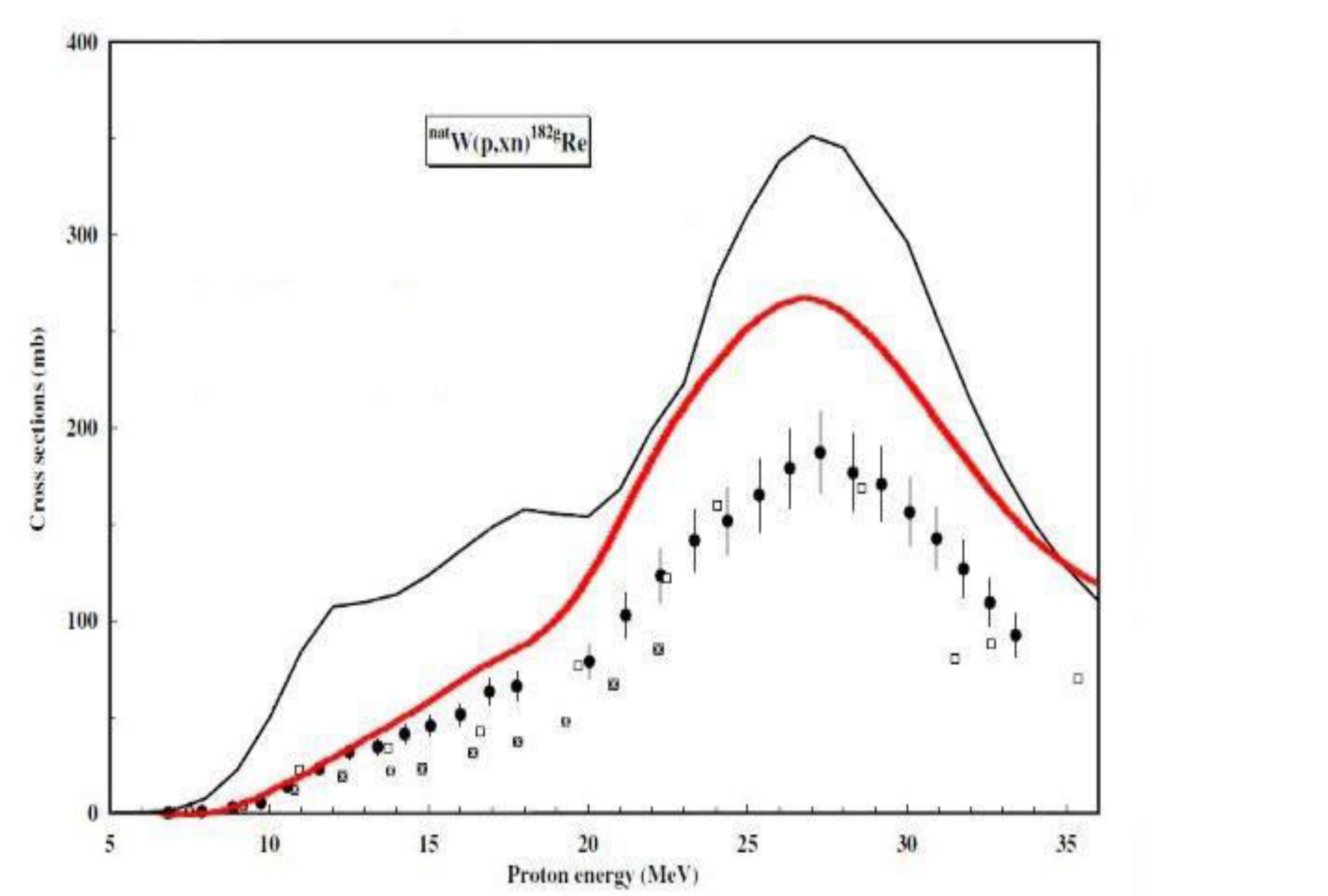


◊- Schoen et al. (1979), + - Zhang et el. (1999), o - Lapi et al. (2006),

∆ - Tarkanyi et al. (2006), • - Khandeker et al. (2007)

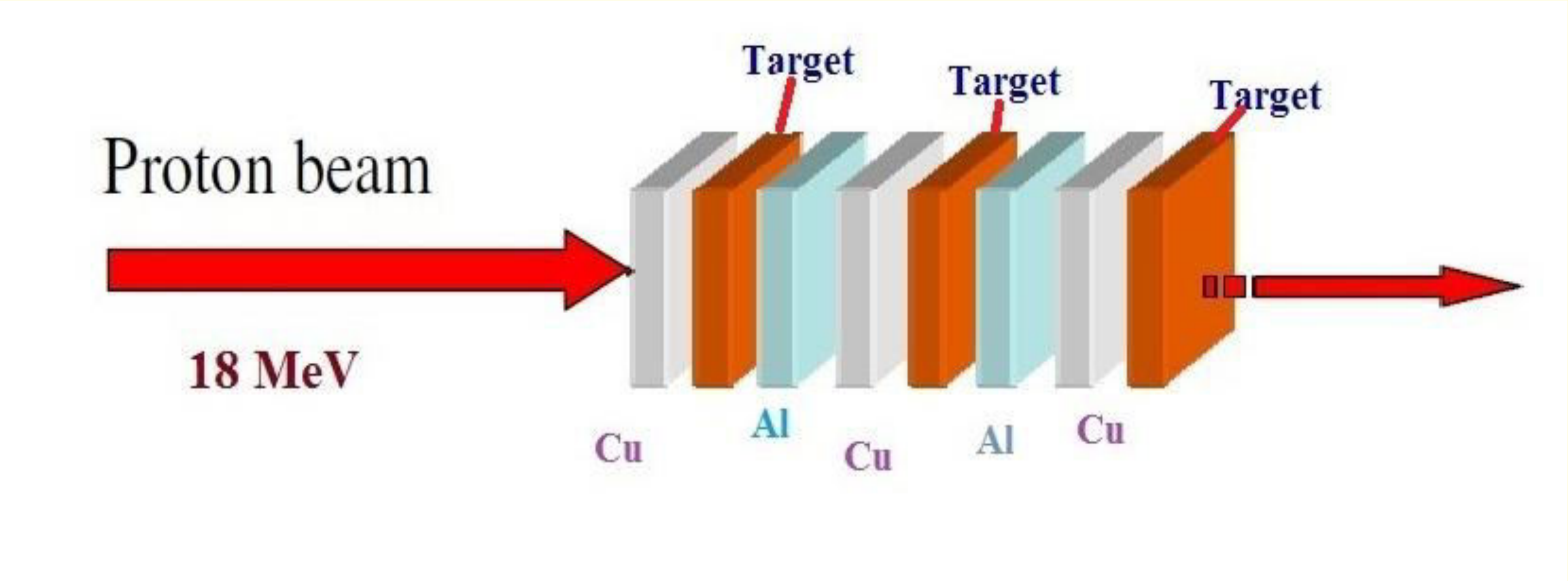
––– ALICE-IPPE, Our calculations: ------ EMPIRE-3.1, ------ Talys 1.4,

----- TENDL2012



- **F. Tarkanyi (2006), * Zhang (1999), □ Michel (2005), Curves: ━ MENDL 2P, ━ TALYS 1.4 (Our result)**

Cyclotron C18/18



Target: ^{NAT}W, ^{NAT}Gd and ^{203}Tl

Al : beam degrader, catcher

Cu: monitor

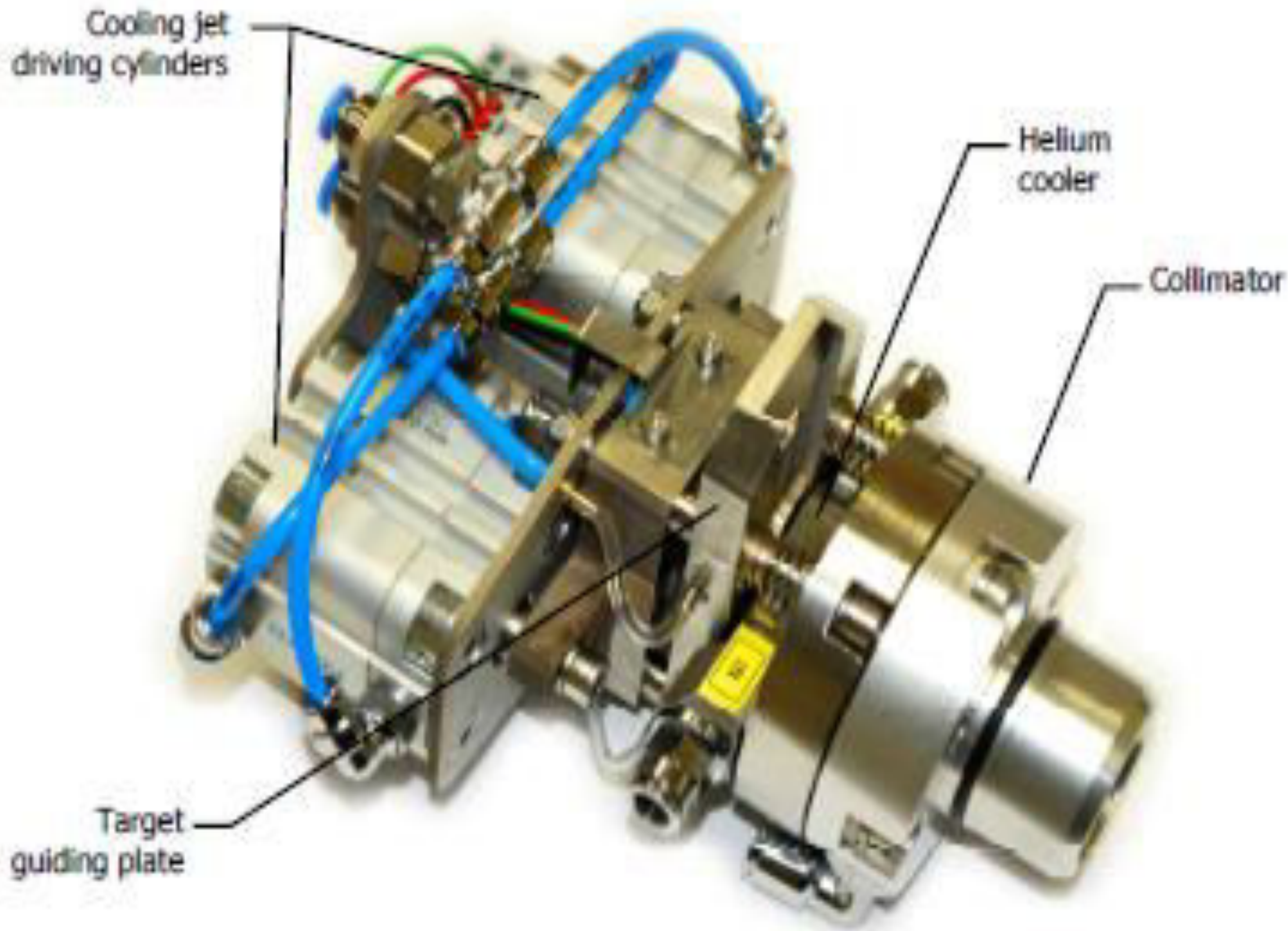
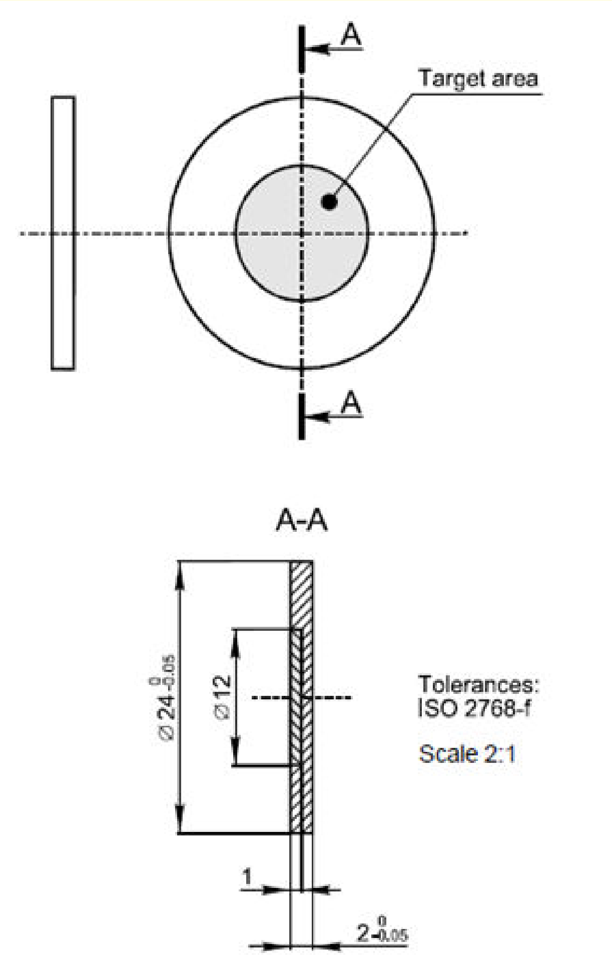


Figure 1.3. *Basic parts of* ***Nirta Solid Compact.***

Target disc sizes and design



If you order:

- ***NSC-TS06-IBA-HA-200 – you will get Havar window foil of 200 μm thickness;***

- ***NSC –TS06-ISO-TI-050 - you will get Titanium window foil of 50 μm thickness;***

- ***NSC-TS06-IBA-AL-500 you will get Aluminum window foil of 500 μm thickness (default configuration for iodine production).***

Havar® - High-Strength Non-Magnetic Alloy

Co42.5/Cr20/Ni13/Fe/W/Mo/Mn – 8.3 g/cm^3,

Melting point - 1480 ℃

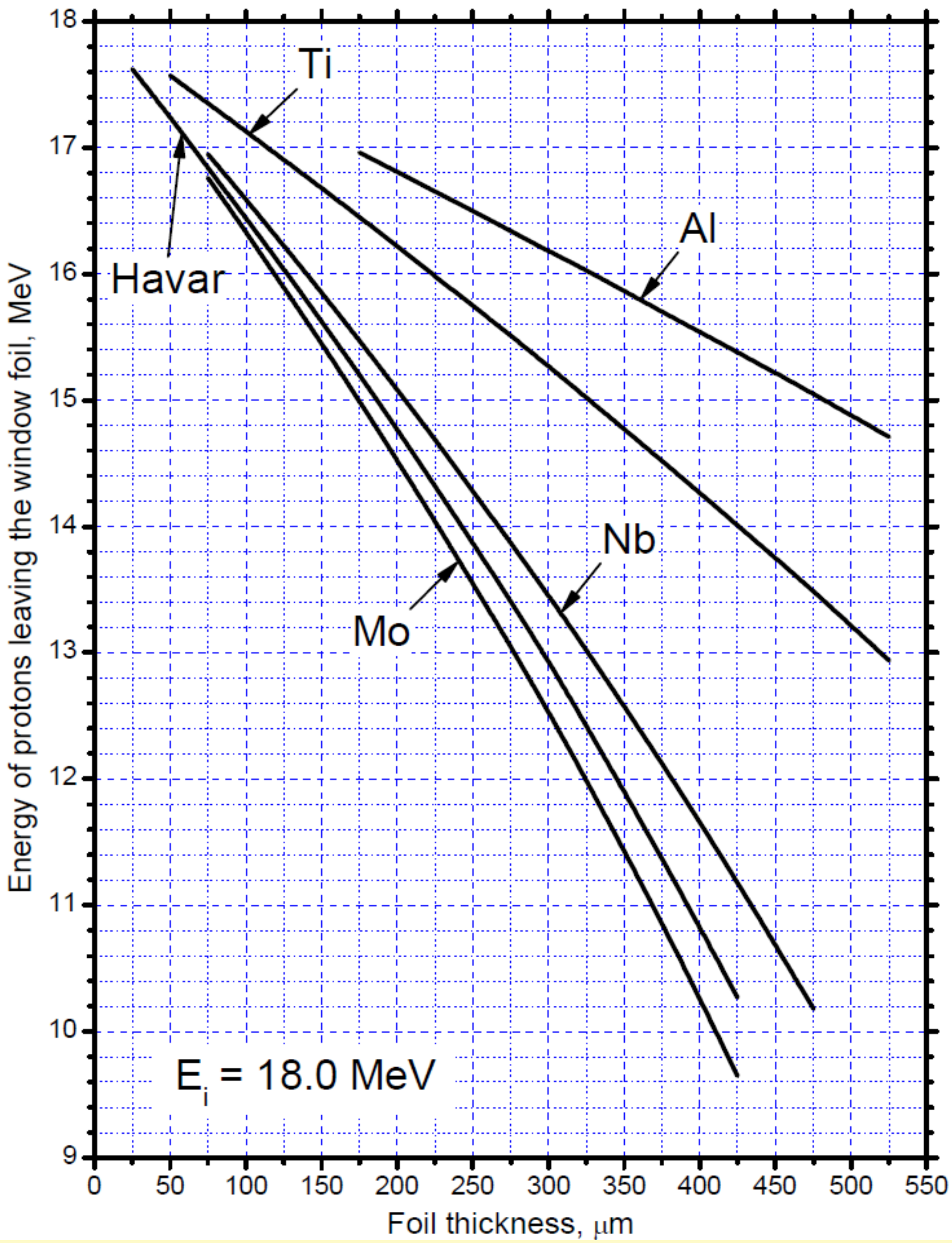
***Aluminum* – 2.7 g/cm^3,**

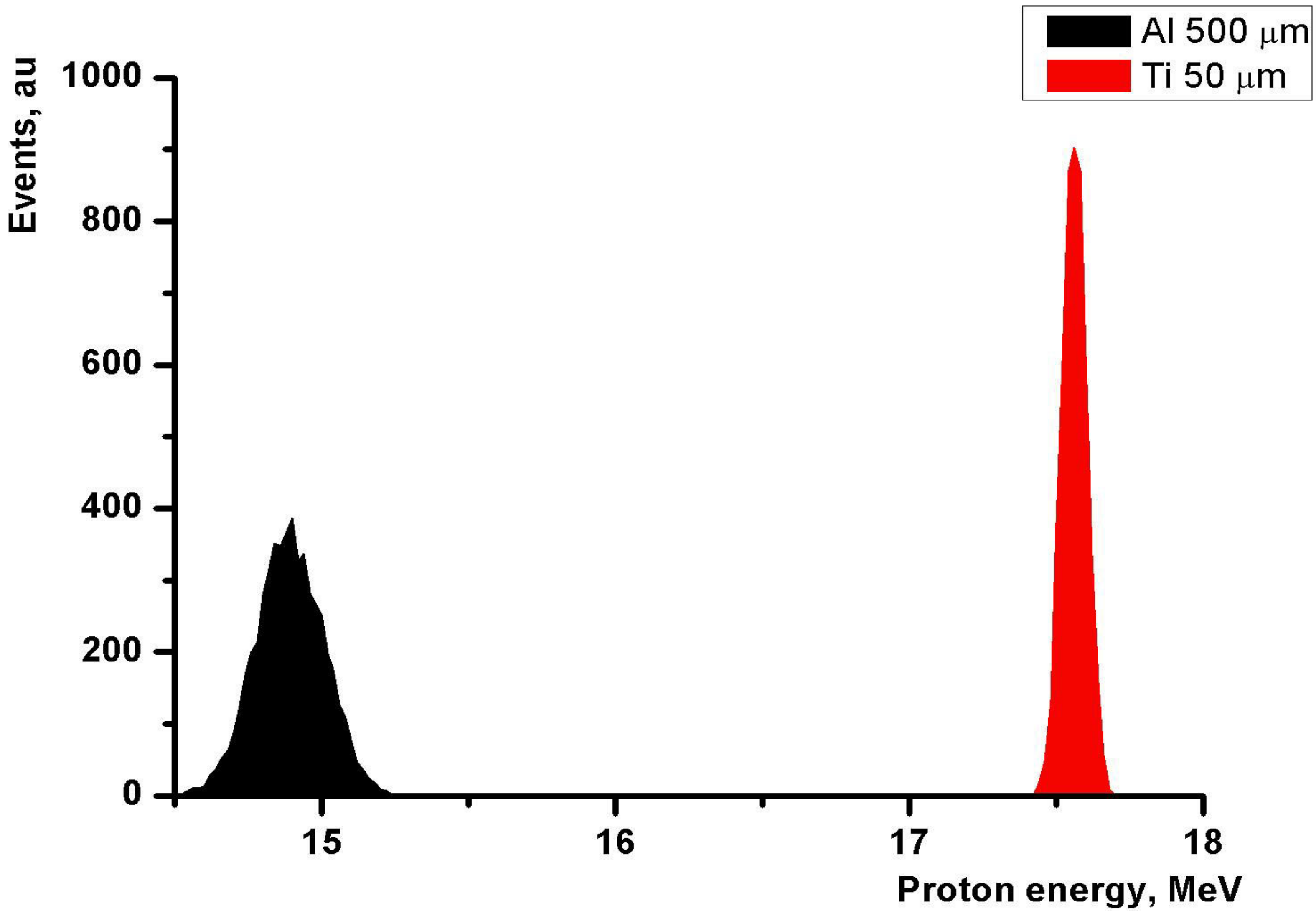
Melting point - 660 ℃

Titanium - 4.5 g/cm^3,

Melting point - 1668 ℃

6.4 Beam energy degradation by the window foil

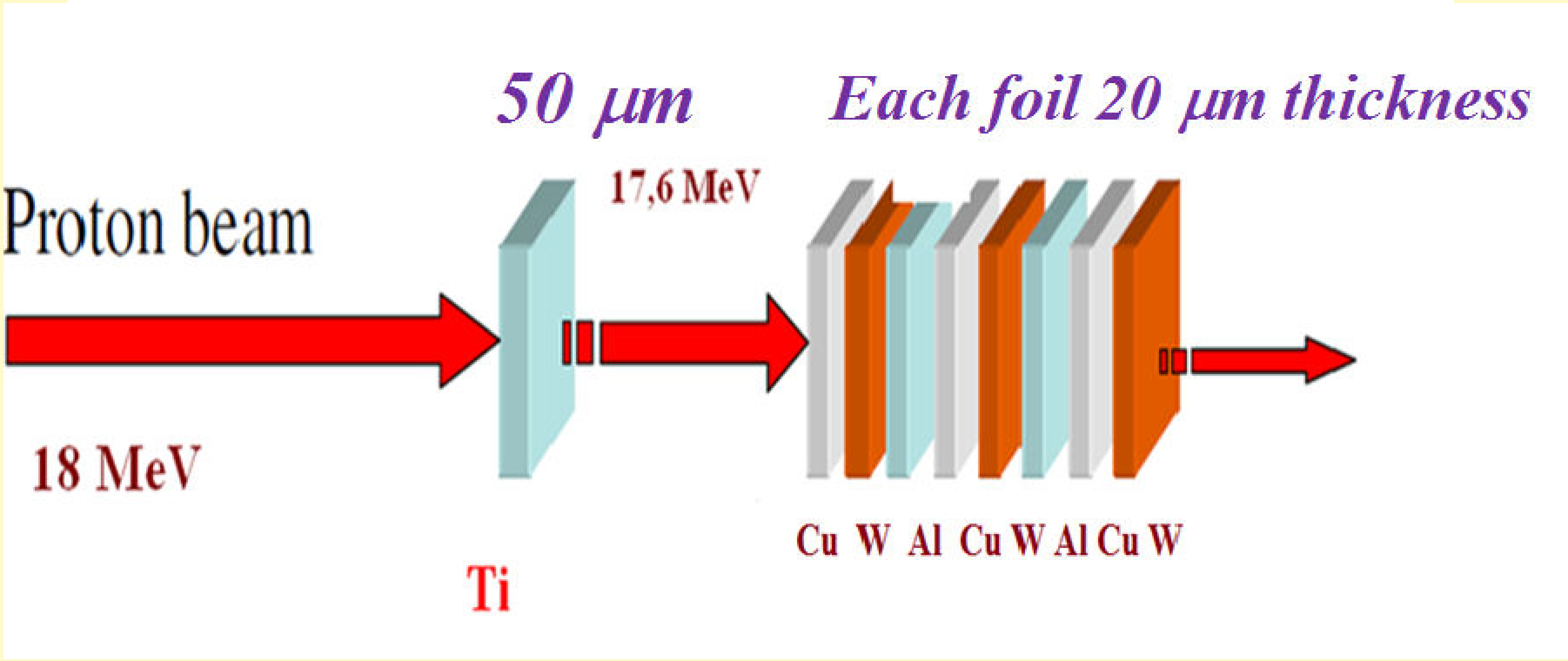




Al 500 μm
Ti 50 μm
Events, au
1000
800
600
400
200
0
15
16
17
18
Proton energy, MeV

In case of foil of the window: Titanium with thickness 50 μm proton beam energy will be 17.57 ± 0.040 MeV.

Aluminum foil with thickness 500 μm proton beam energy will be 14.88 ± 0.129 MeV.



50 μm
Each foil 20 μm thickness
Proton beam
17,6 MeV
18 MeV
Cu W Al Cu W Al Cu W
Ti

$^{nat}W(p,xn)^{182m,182g,183,184m,184g,186g}Re$

Isotope	Natural abundance, %
^{180}W	0.12
^{182}W	26.50
^{183}W	14.31
^{184}W	30.64
^{186}W	28.43

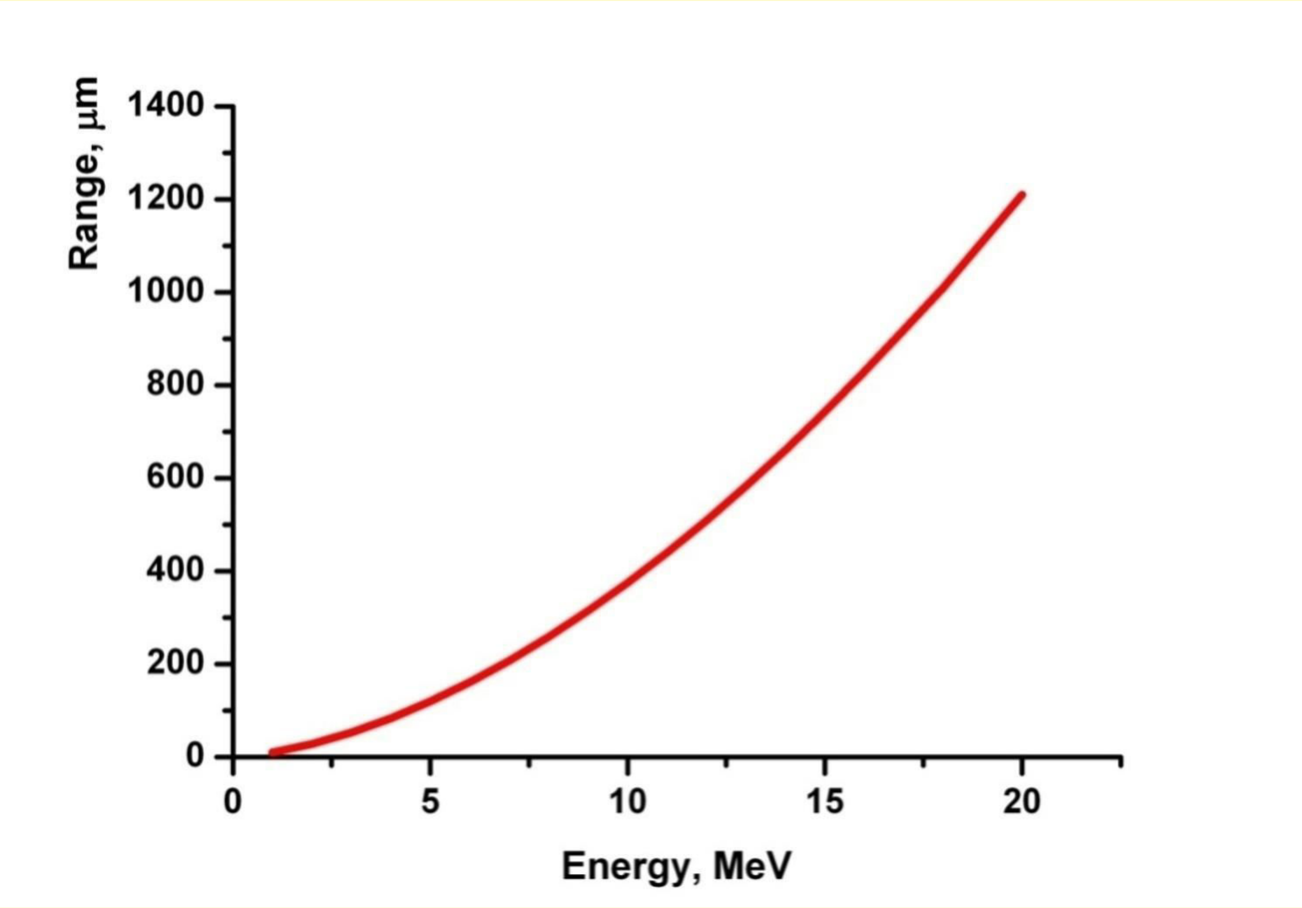
Nuclei	Half-life	Reactions	Threshold, MeV	E_γ, keV	Intensity, (%)
^{181}Re	20 h	$^{182}W(p,2n)$	10.5	365.57	57.
^{182g}Re	64 h	$^{182}W(p,n)$	3.58	169.15	11.3
		$^{183}W(p,2n)$	9.77		
^{182m}Re	12.7 h	$^{182}W(p,n)$	3.58	470.32	2.
		$^{183}W(p,2n)$	9.77		
^{183}Re	70 d	$^{183}W(p,n)$	1.35	162.32	23.3
		$^{184}W(p,2n)$	8.75		
^{184g}Re	38 d	$^{184}W(p,n)$	2.27	792.07	37.5
^{184m}Re	169 d	$^{184}W(p,n)$	2.27	104.73	13.4
^{186}Re	3.72 d	$^{186}W(p,n)$	1.36	137.16	9.42

SRIM ***(Stopping and Range of Ions in Matter) is a group of programs which calculate the stopping and range of ions (up to 2 GeV/amu) into matter using a quantum mechanical treatment of ion-atom collisions***

TRIM (Transport of Ions in Matter)

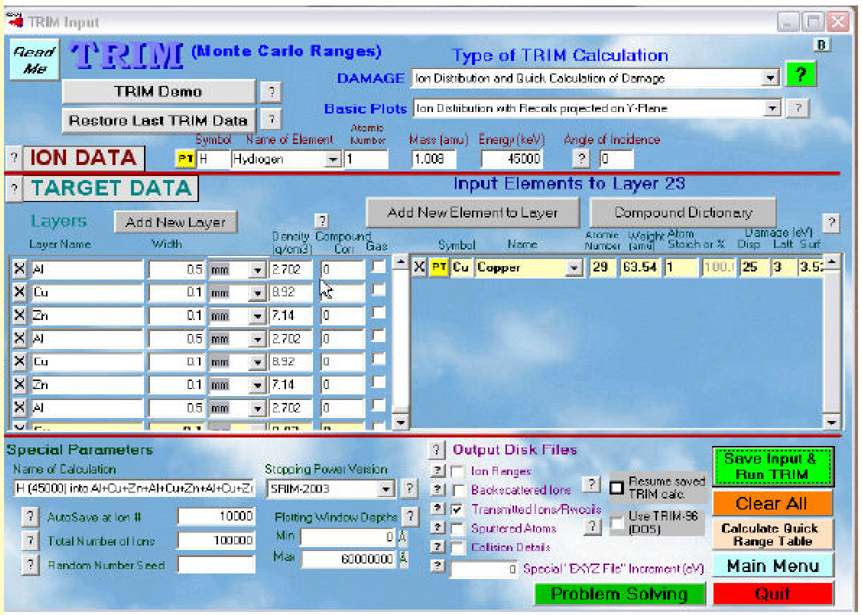
SSSM (SRIM Support Software Module)

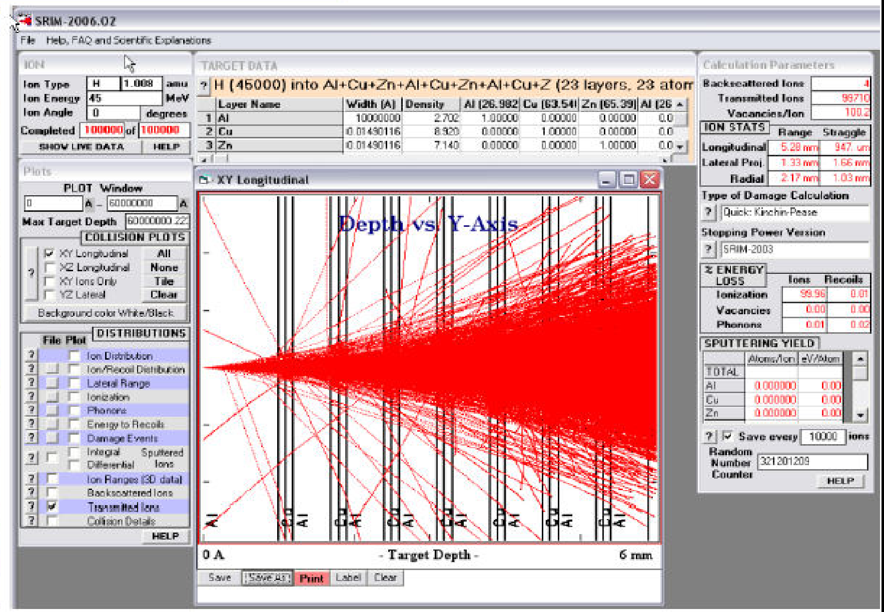
The beam-energy degradation and proton range in the W-target stack was determined using the computer code SRIM-2013



For the determination of optimum target thickness and calculation of proton beam energy degradation for all investigated nuclei SRIM-2013 (SRIM/TRIM – Stopping and Range of Ion in Matter/Transport of Ions in Matter) nuclear code was used.

Calculation of proton beam energy degradation

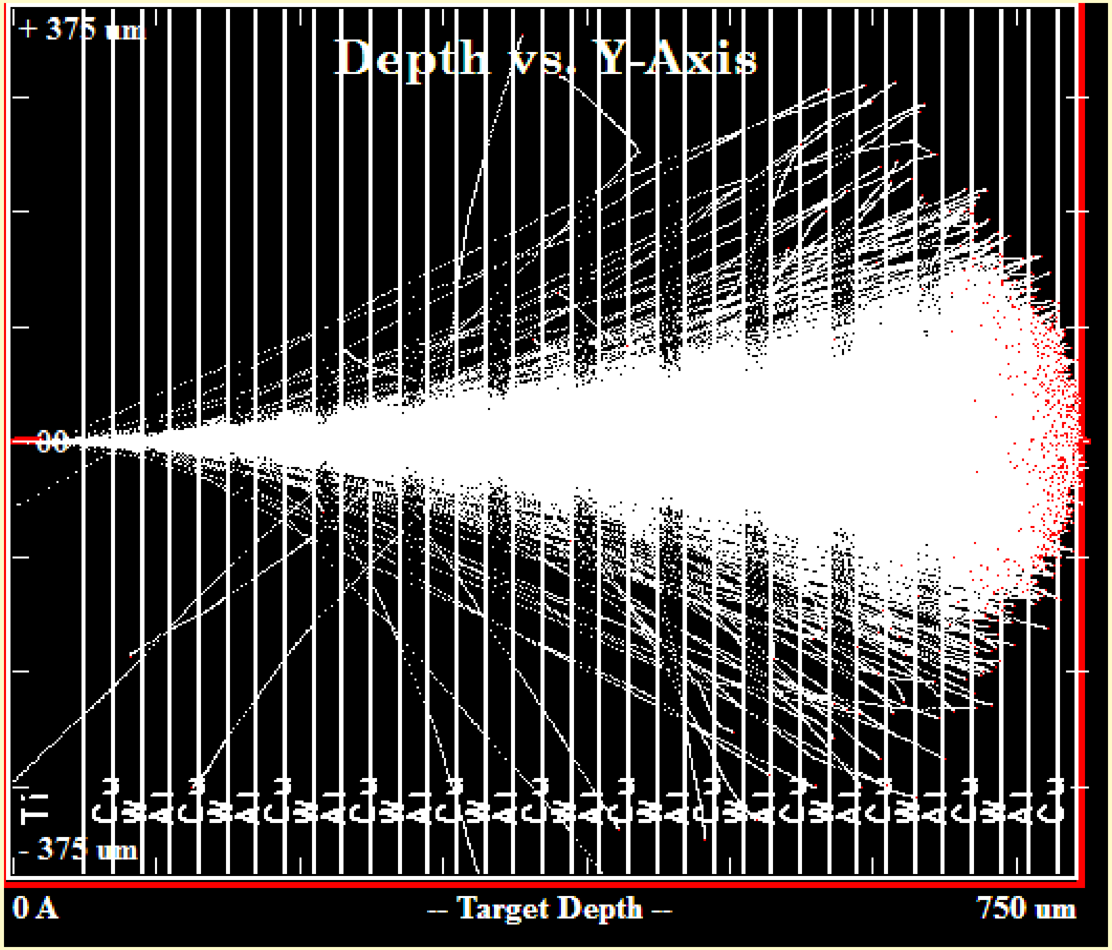


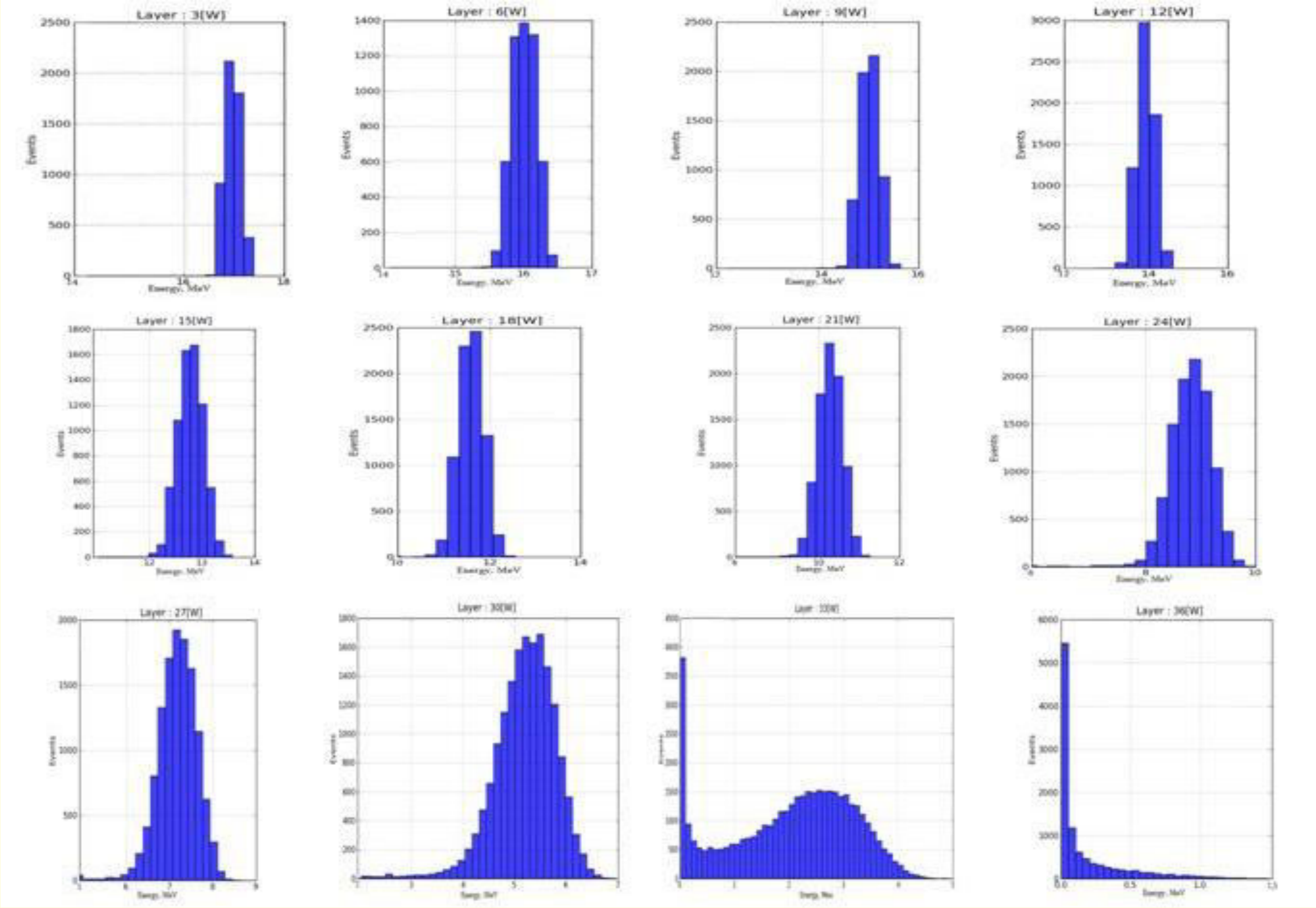


http://www.srim.org

- SRIM(The Stopping and Range of Ions in Matter) : Monte Carlo Transport Calculation
- Calculate the stopping and range of ions

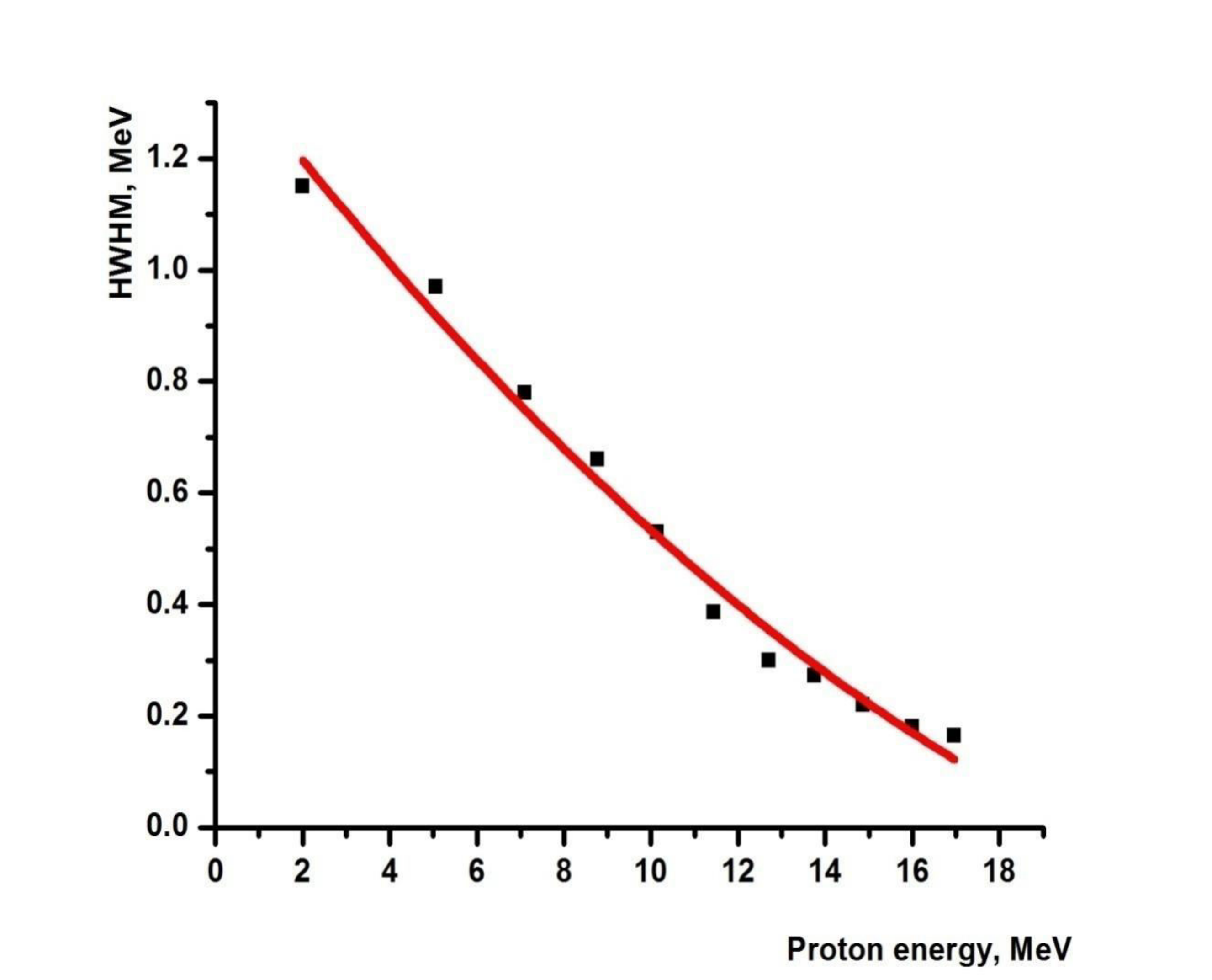
Transport of protons through stack





Energy distribution of proton beam at W foils

W foil number	Energy, MeV
1	16.96 ± 0.165
2	16.00 ± 0.18
3	14.87 ± 0.22
4	13.76 ± 0.273
5	12.71 ± 0.3
6	11.45 ± 0.386
7	10.15 ± 0.53
8	8.77 ± 0.66
9	7.11 ± 0.78
10	5.07 ± 0.97
11	2.01 ± 1.15


HWHM, MeV
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
16
18
Proton energy, MeV

After irradiation the stacks are disassembled, so that W and Cu corresponding foils can be taken together for subsequent γ-ray spectroscopy.

Detector HPGe – ORTEC
Analyzer DSPEC-LF Digital +MAESTRO

$$\sigma = \frac{\lambda C}{\varepsilon * I\gamma * Nd * l * \phi(1 - e^{-\lambda tm})e^{-\lambda tc}(1 - e^{-\lambda ti})}$$

λ - the decay constant of isotope of interest, $\lambda=0.693/T_{1/2}$;
C – total counts of gamma-ray peak area;
ε - the efficiency of the detector for the radiation of interest;
I_γ - the branching ratio or intensity of the gamma ray of interest;
N_d - atomic density (atom/cm^3);
l - foil thickness, cm
ϕ - the incident proton flux (p/cm^2/s);
t_c, t_m, t_i - the cooling time, measuring time, irradiating time (s).

Determination of beam flux

$$\phi = \frac{\lambda C}{\varepsilon \times I_\gamma \times N_d \times t \times \sigma (1 - e^{-\lambda t_m}) e^{-\lambda t_c} (1 - e^{-\lambda t_i})}$$

For Cu cooper

Monitor Reactions. Protons. Deuterons. 3He-particles. Alpha-particles.

http://www-nds.iaea.org/medical/monitor_reactions.html

Table of NMR-active nucleus properties of copper

Isotopes	*Natural abundance, %*	*Reactions*	*Threshold, MeV*	*Half-life*	*Eγ, keV*	*Intensity, %*
^{63}Cu	69.17	$^{nat}Cu(p,x)\ ^{62}Zn$	4.21	9.186 h	596.56 507.6	26. 14.8
^{65}Cu	30.83	$^{nat}Cu(p,x)\ ^{65}Zn$	2.17	244.26 d	1115.55	50.60

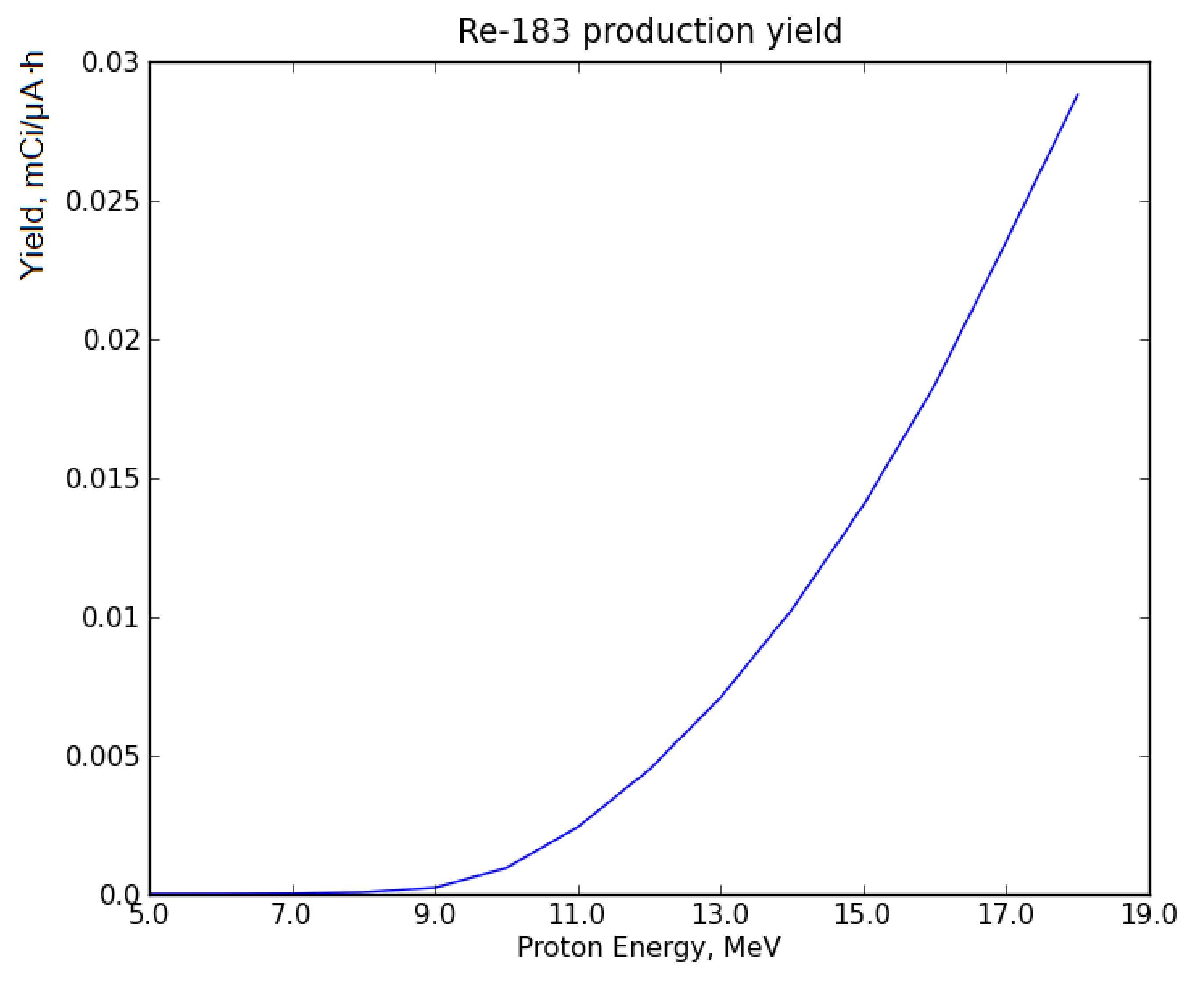
$$\sigma = \frac{\lambda C}{\varepsilon \times I_\gamma \times N_d \times t \times \phi (1 - e^{-\lambda t_m}) e^{-\lambda t_c} (1 - e^{-\lambda t_i})}$$

For investigated nuclei

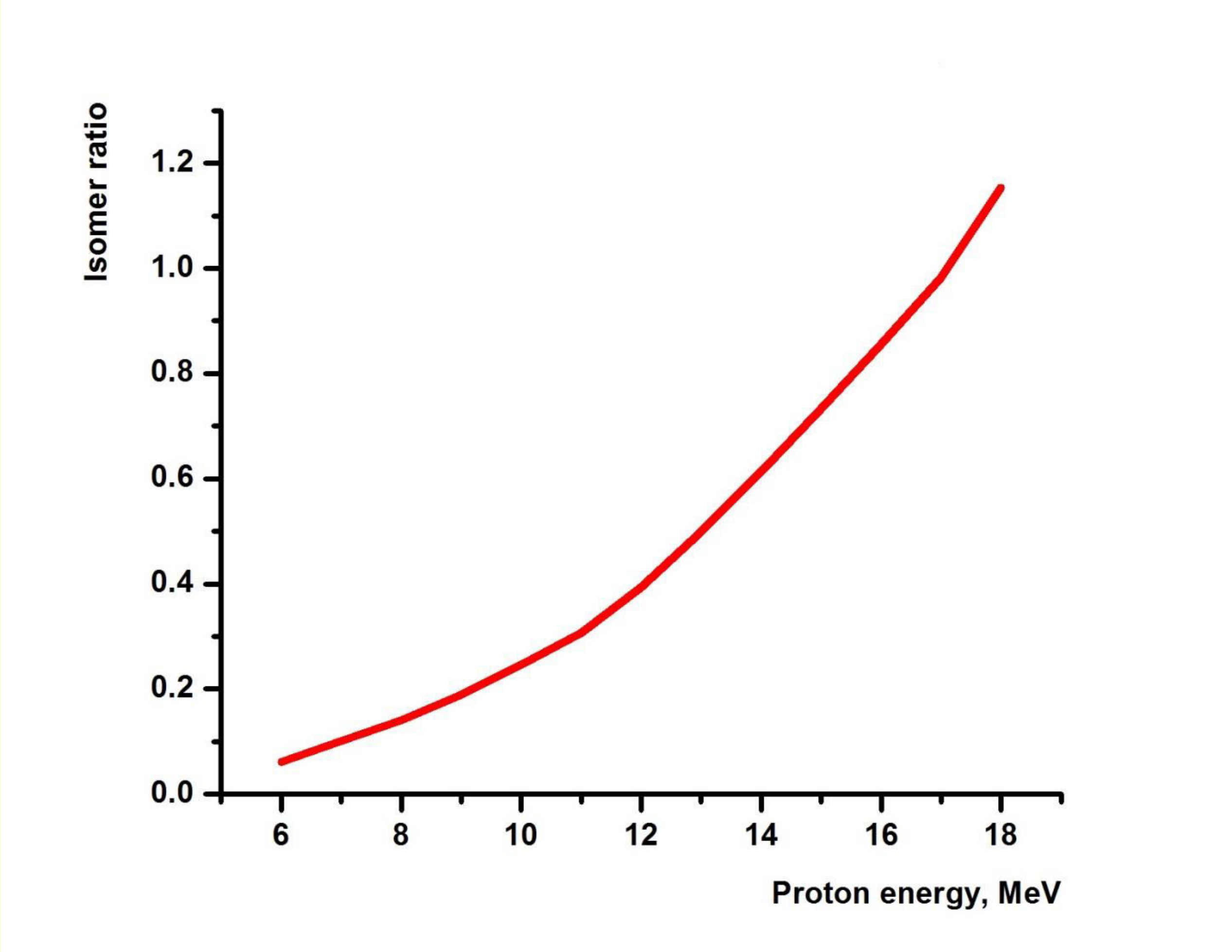
The total errors associated with cross section measurements is calculated by quadratic summing the possible individual relative errors:

- *Counting statistics;*
- *Detector efficiency;*
- *Decay data;*
- *Number of target nuclei;*
- *Incident bombarding particle intensity.*

$$Y = 6.24 \, x \, 10^{12} \, x \frac{N_A}{M} \int_{Eout}^{Ein} \frac{\sigma(E)}{S(E)} dE$$



Calculated by TALYS isomer ratio $\sigma(^{182g}Re)/\sigma(^{182m}Re)$



Publications

1. R.Avakian, G.Bazoyan, M.Hakobyan, I.Kerobyan, “The Possibility of the Neutron Beams Formation on Base of Cyclotron C18”, Procc. X International Symposium “RREPS-13” and “Meghri-13”, September 23-27, 2013, Yerevan, Armenia

2. R.Avagyan, R.Avetisyan, G.Bazoyan, M.Hakobyan, I.Kerobyan, “Evaluation of the yields of Ga-67 produced on cyclotron C18”, AJP 7(2) 2014

3. A.Avetisyan, R.Avagyan, R.Dallakyan, I.Kerobyan “Photo-production of $^{99}Mo/^{99m}Tc$ with electron linear accelerator beam”, Nuclear Medicine and Biology (Accepted for publication)

4. А.С.Данагулян, Г.О.Оганесян, Т.М.Бахшиян, Р.О.Авакян, А.Э.Аветисян, И.А.Керобян, Р.К.Даллакян “Фотоядерные реакции на мишенях $^{112,116,124}Sn$, ^{нат}Te, ^{нат}Hf “, Ядерная Физика

5. A.Danagulyan, G.Hovhanissyan, T.Bakhshiyan, R.Avagyan, A.Avetisyan, I.Kerobyan, R.Dallakyan “Formation of the medical radionuclides ^{111}In, ^{117m}Sn, ^{124}Sb and ^{177}Lu in photonuclear reactions”, Applied Radiation and Isotopes

THANK YOU!

Publications

1. R.H.Avagyan, A.E.Avetisyan, I.A.Kerobyan, S.P.Taroyan, The Applied Physics at Yerevan Physics Institute, Proceedings of National Academy of Science of Armenia, 44, 5, 2009, pp. 380-388.
2. R.H.Avagyan, A.E.Avetisyan, I.A.Kerobyan et al., Experimental Plant for Investigation of the Possibility of Production of Medicine Intended Isotopes on the Base of Linear Accelerator, 47, 1, 2012, pp. 9-16.
3. A.Avetisyan, R.Avagyan, R.Dallakyan, I.Kerobyan, "^{99m}Tc photo-production under electron linear accelerator beam", Armenian Journal of Physics, 2013, vol. 6, issue 1, pp. 35-44.
4. R.Avakian, G.Bazoyan, M.Hakobyan, I.Kerobyan, "The Possibility of the Neutron Beams Formation on Base of Cyclotron C18", Procc. X International Symposium "RREPS-13" and "Meghri-13", September 23-27, 2013, Yerevan, Armenia
5. R.Avagyan, R.Avetisyan, G.Bazoyan, M.Hakobyan, I.Kerobyan, "Evaluation of the yields of Ga-67 produced on cyclotron C18", AJP 7(2) 2014
6. A.Avetisyan, R.Avagyan, R.Dallakyan, I.Kerobyan "Photo-production of ^{99}Mo/^{99m}Tc with electron linear accelerator beam", Nuclear medicine and Biology