NUCLEAR REACTION MODELS FOR SYSTEMATIC ANALYSIS OF FAST NEUTRON INDUCED (n,p) REACTION CROSS SECTIONS

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MOTIVATION

Investigation of fast neutron induced charged particle emission reactions is important:

1. Fundamental nuclear physics study:
   - The study of nuclear reactions mechanisms
   - Nuclear structure
2. Fission and fusion reactors technology:
   - Radiation damage
   - Residual radioactivity
   - Hydrogen and helium gas production

Systematical analysis of neutron cross sections is of interest:

1. To evaluate of neutron cross sections
2. To estimate of authenticity for experimental data

V.N. Levkovsky, Sov.J.Nucl.Phys. 18, N4, 1973, p.705

Empirical formula σ(n,p) and σ(n,α) at E_n=14-15 MeV

$$\sigma(n,p) = C\pi r_0^2 (1 + A^{1/3})^2 e^{-K\frac{N-Z}{A}}$$

Here: C=0.73 and, K=33 are fitting parameters.

G.Khuukhenkhuu, JINR preprint. E3-93-205, Dubna, 1993

Compound Mechanism: **N.Bohr, Nature, v.137 (1936), p.344**

Statistical Model: **J.M.Blatt, V.F.Weisskopf, Theoretical Nuclear Physics, John Wiley and Sons, New York, (1952)**

Pre-equilibrium Mechanism: **J.Griffin, Phys.Rev.Lett. vol.17, 1966, p.478**

Exciton Model

Direct Reaction Mechanism: **J.R.Oppenheimer, M.Philips. Phys.Rev., v.48, N6, 1935, p.500**

Plane Wave Born Approximation

– Statistical Model:

G.Khuukhenkhuu, G.Unenbat, M.Odsuren *et al.*
JINR Preprint, E3-2007-25,Dubna, 2007, -12p.

$$\sigma_{np}^{com} = C\pi(R+\lambda\!\!\!^{-})^2 e^{-K\frac{N-Z+1}{A}} \qquad (1)$$

$$C = \exp\frac{1}{\Theta}\left(\gamma\frac{2Z-1}{A^{1/3}} + \frac{\Delta}{A^{3/4}} - V_p\right) \qquad K = \frac{4\xi}{\Theta}$$

Here:

R, *Z, N and A* - radius, proton, neutron and mass numbers of target nuclei

$\lambda\!\!\!^{-}$ - Wavelength of incident neutrons divided by 2π

V_p - Coulomb potential for protons

Θ- Thermodynamic temperature of nuclei

ξ and $\Delta=\delta_i-\delta_f$ - Constants of Weizsacker's formula.

– Exciton Model:

G.Khuukhenkhuu, G.Unenbat, M.Odsuren *et al.*
JINR Preprint, E3-2007-26, Dubna, 2007, -5p.

$$\sigma_{np}^{pre} = 68.3\frac{\pi^6}{\hbar^2}R^2\sigma_r(E_n)\frac{2M_p}{K_0 A}\frac{\left[(E_n+Q_{np})-V_p\right]^3}{(E_n+B_n)^3} \qquad (2)$$

Where:

$\sigma_r(E_n)$ -Neutron induced reaction total cross section

M_p - Mass of proton

$K_0 \approx 400\ \mathrm{MeV}^3$

E_n and B_n - Kinetic and binding energy of neutron

Q_{np} - Reaction energy

– Plane Wave Born Approximation:

G.Khuukhenkhuu, G.Unenbat, M.Odsuren *et al.*
JINR Preprint, E3-2007-27, Dubna, 2007, -7p

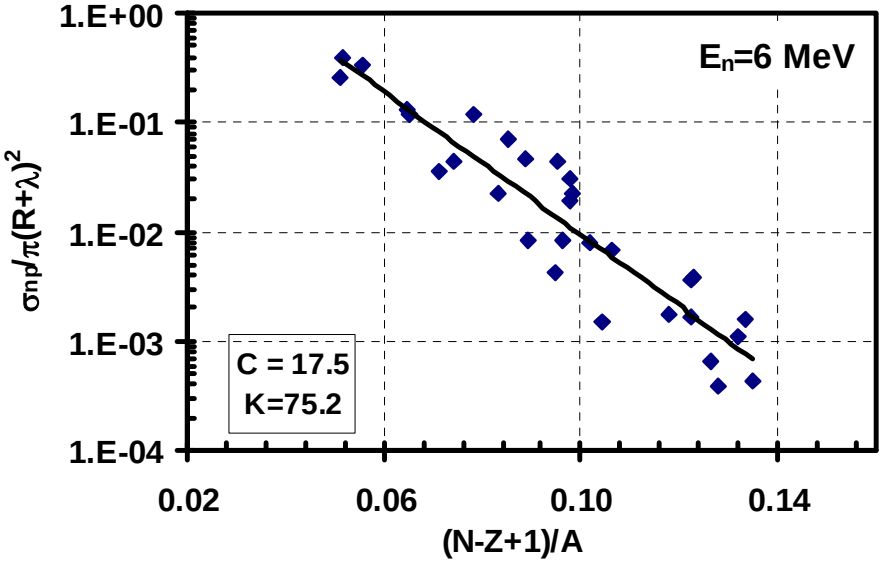
$$\sigma_{np}^{dir} = C_0\pi R^2\sqrt{1+\frac{Q_{np}}{E_n}} \qquad (3)$$

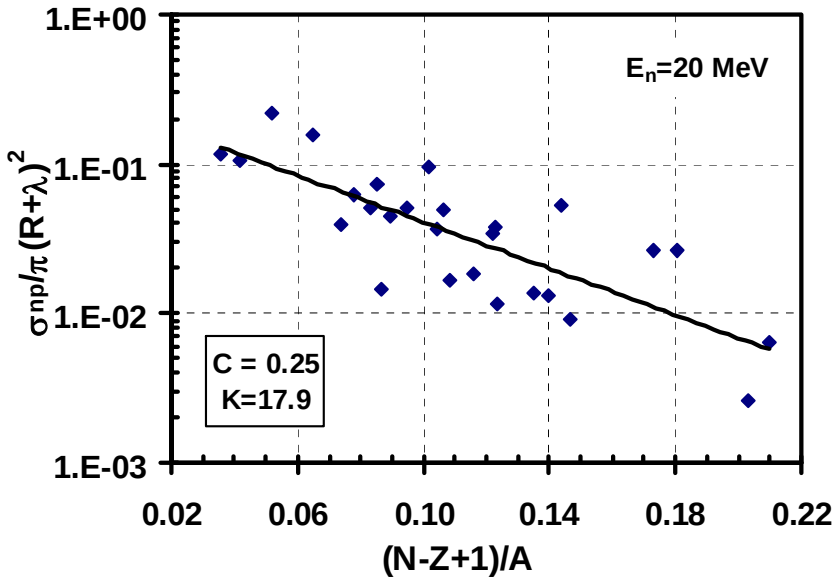
Where C_0 can be determined as best fitting the experimental data parameter.

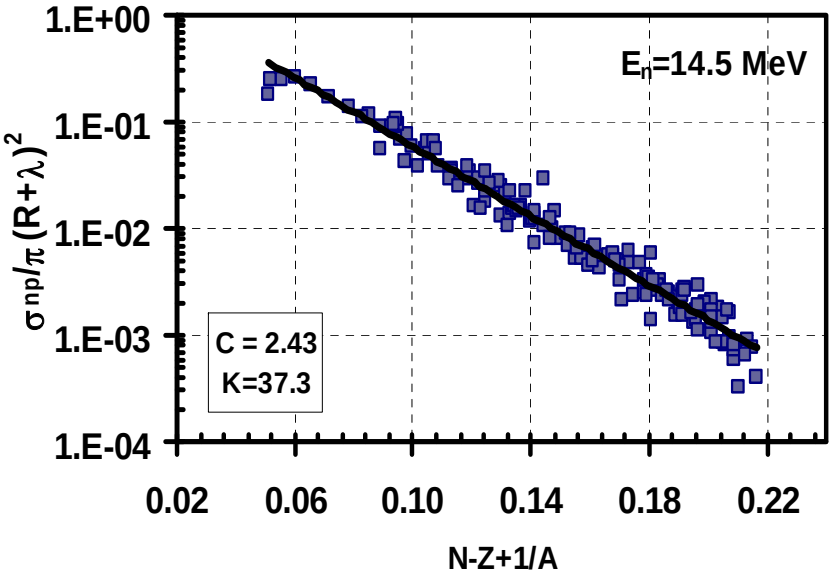
Theoretical total (n,p) cross section:

$$\sigma_{np}^{tot} = \sigma_{np}^{com} + \sigma_{np}^{pre} + \sigma_{np}^{dir}$$

SYSTEMATICS OF THE (n,p) REACTION CROSS SECTIONS



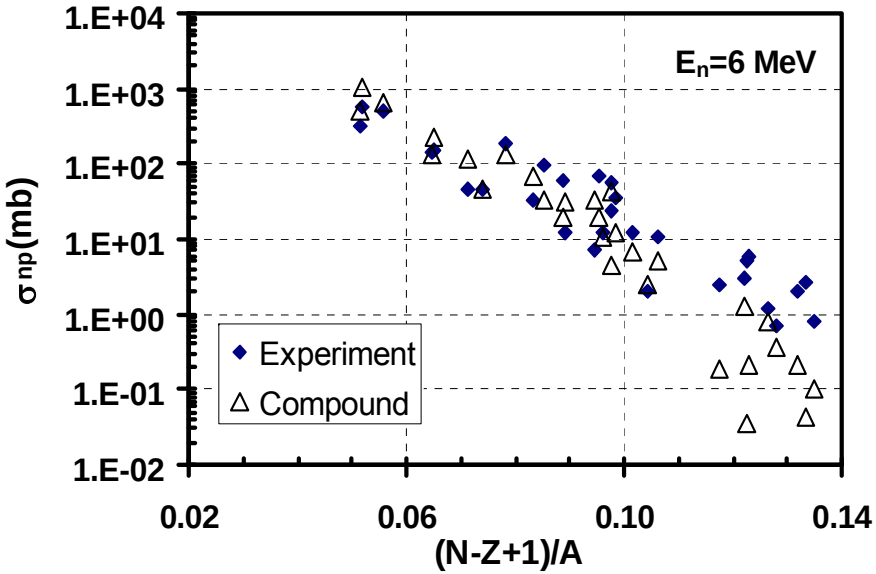


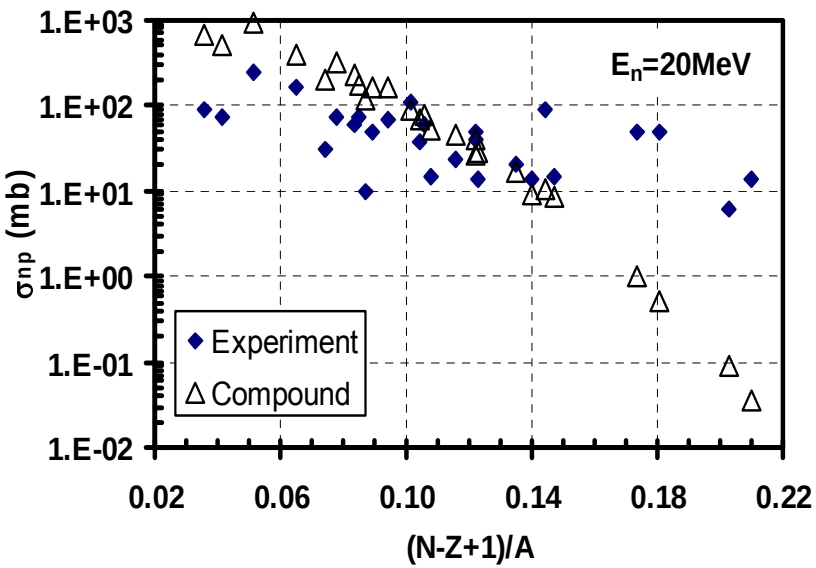


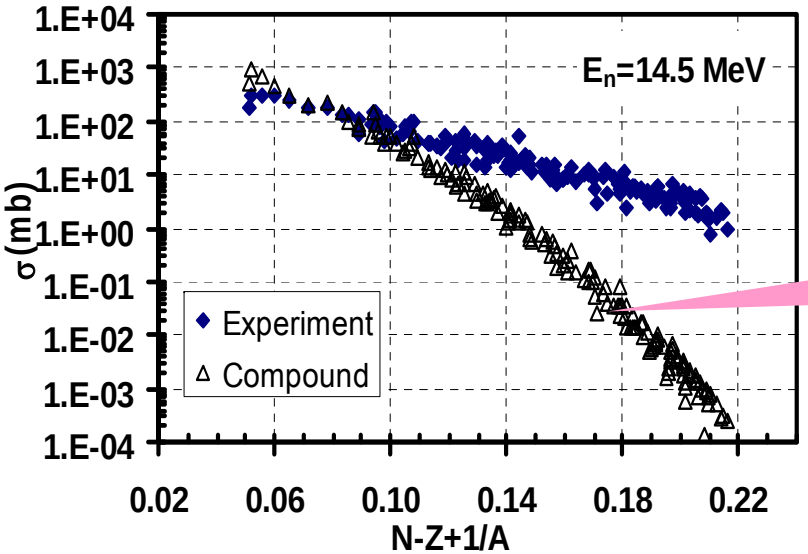
E_n (MeV)	K	C
6	75.2	17.5
8	62.8	11.9
10	52.1	6.80
13	38.8	2.74
14.5	37.3	2.43
16	33.5	1.42
18	22.4	0.39
20	17.9	0.25

COMPARISON OF EXPERIMENTAL AND THEORETICAL (n,p) CROSS SECTIONS

Statistical model (n,p) cross sections and experimental data:

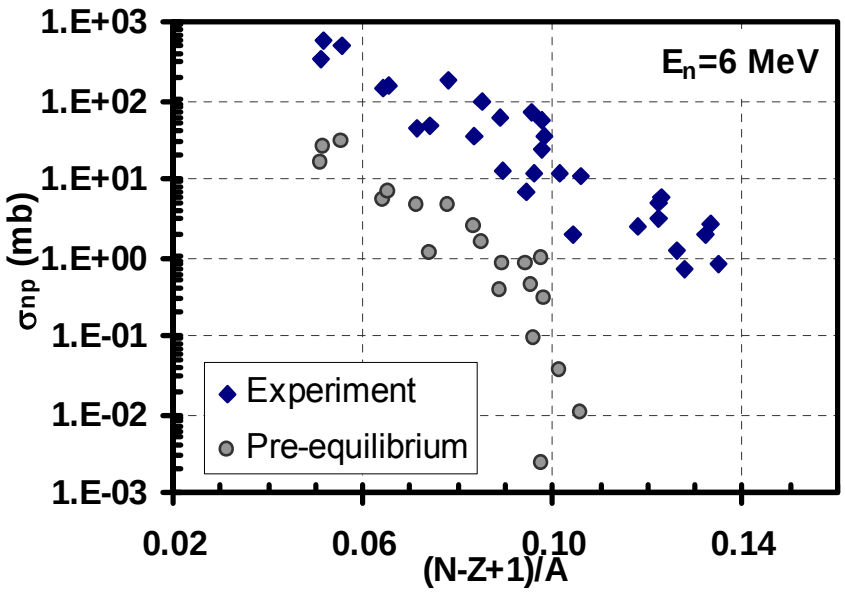


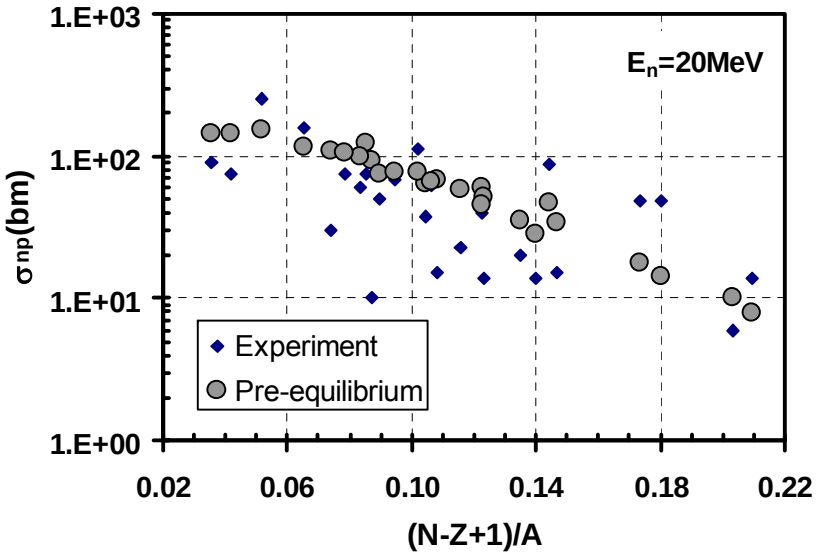


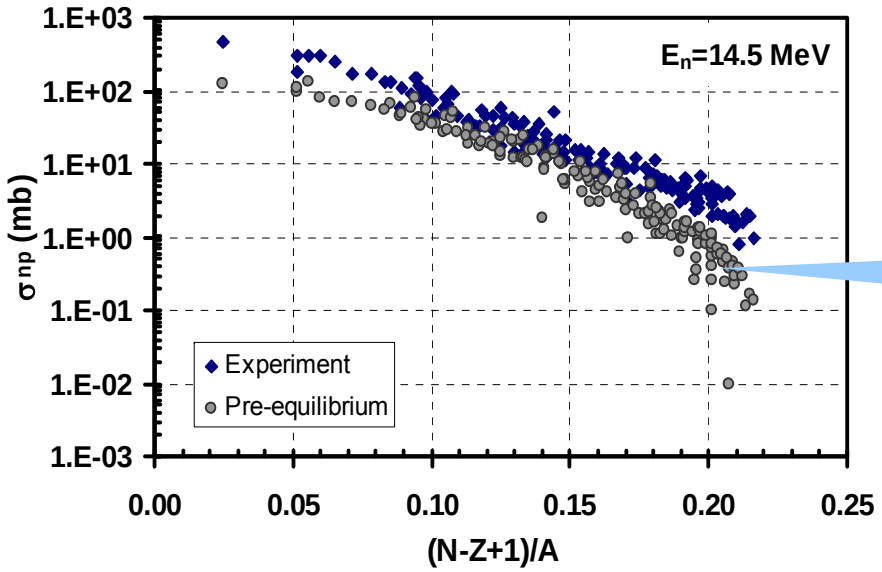


$$\sigma_{np}^{com} = C\pi(R+\lambda\!\!\!^{-})^2 e^{-K\frac{N-Z+1}{A}}$$

Exciton model (n,p) cross sections and experimental data:

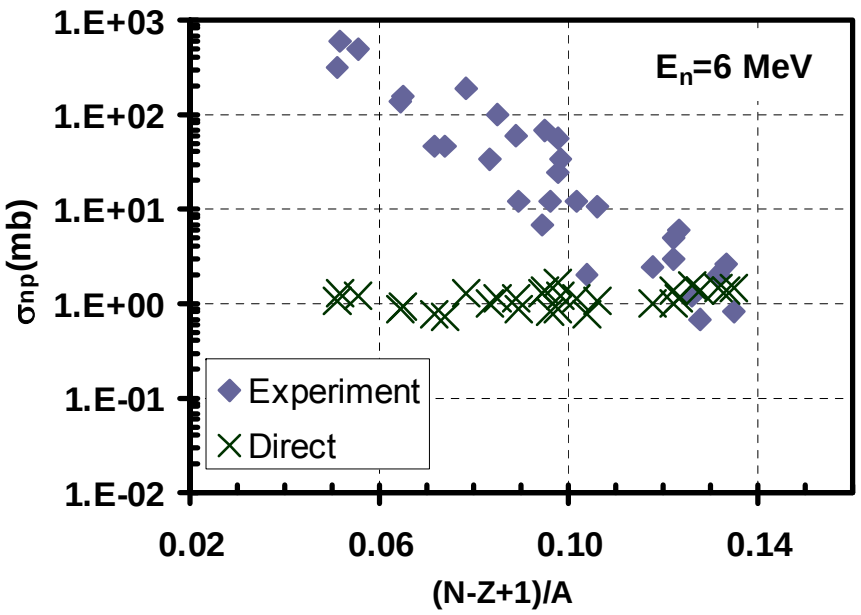


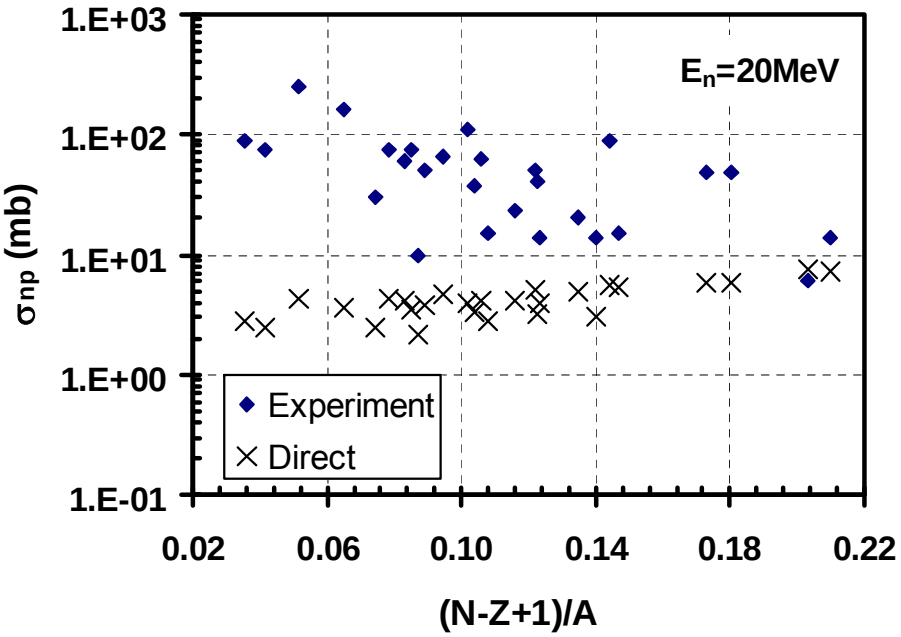


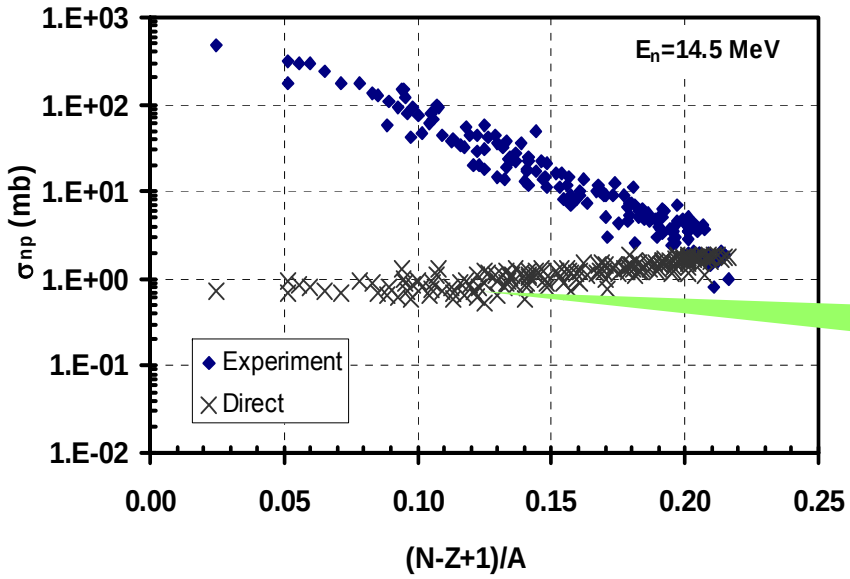


$$\sigma_{np}^{pre} = 68.3\frac{\pi^6}{\hbar^2}R^2\sigma_r(E_n)\frac{2M_p}{K_0A}\frac{\left[(E_n+Q_{np})-V_p\right]^3}{(E_n+B_n)^3}$$

PWBA (n,p) cross sections and experimental data:

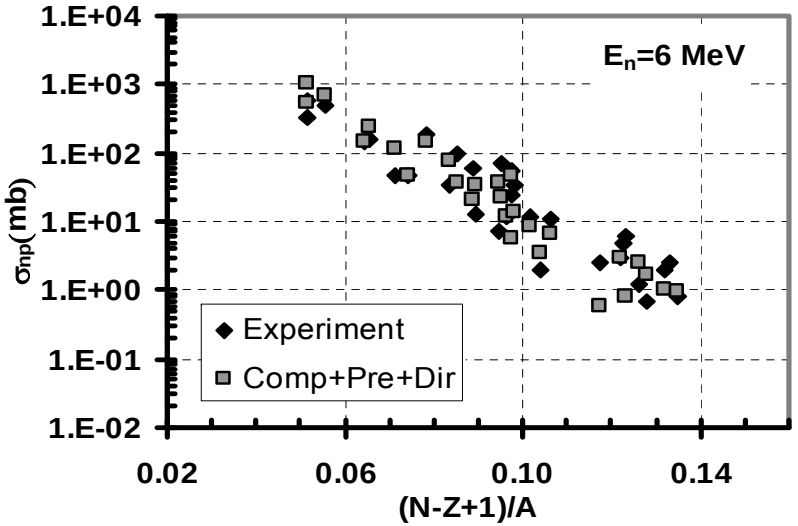


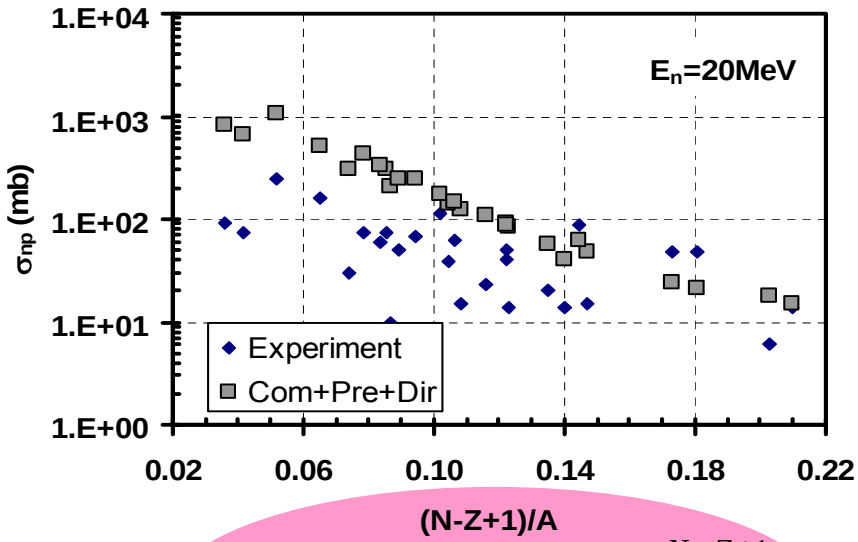


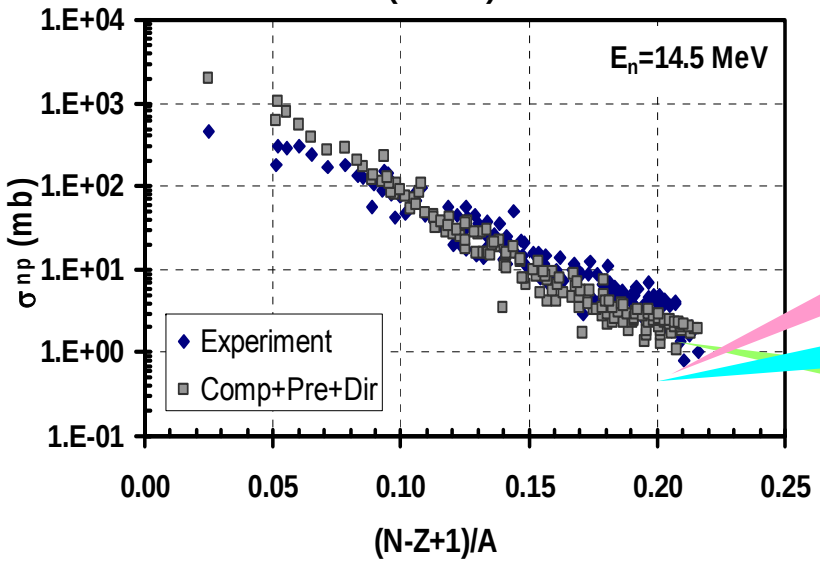


$$\sigma_{np}^{dir} = C_0 \pi R^2 \sqrt{1 + \frac{Q_{np}}{E_n}}$$

The total (n,p) cross section $\sigma_{np}^{tot} = \sigma_{np}^{com} + \sigma_{np}^{pre} + \sigma_{np}^{dir}$







$$\sigma_{np}^{com} = C\pi(R+\lambda\!\!\!^{-})^2 e^{-K\frac{N-Z+1}{A}}$$

$$\sigma_{np}^{pre} = 68.3\frac{\pi^6}{\hbar^2}R^2\sigma_r(E_n)\frac{2M_p}{K_0 A}\frac{\left[(E_n+Q_{np})-V_p\right]^3}{(E_n+B_n)^3}$$

$$\sigma_{np}^{dir} = C_0\pi R^2\sqrt{1+\frac{Q_{np}}{E_n}}$$

The theoretical total (n,p) cross sections are satisfactorily in agreement with experimental values for E_n=6, 14.5 and 20 MeV. Also, in the case of E_n=8, 10, 13, 16 and 18 MeV neutrons we have almost the same results.

CONCLUSION

1. Using the statistical model, exciton model and PWBA are deduced formulae for the fast neutron induced (n,p) reaction cross sections.
2. The formulae were used for systematical analysis of fast neutron induced (n,p) reaction cross sections.
3. It was shown that the theoretical and experimental total (n,p) cross sections for E_n=6-20 MeV are satisfactorily in agreement.

Thank you for your attention

MONGOLIA

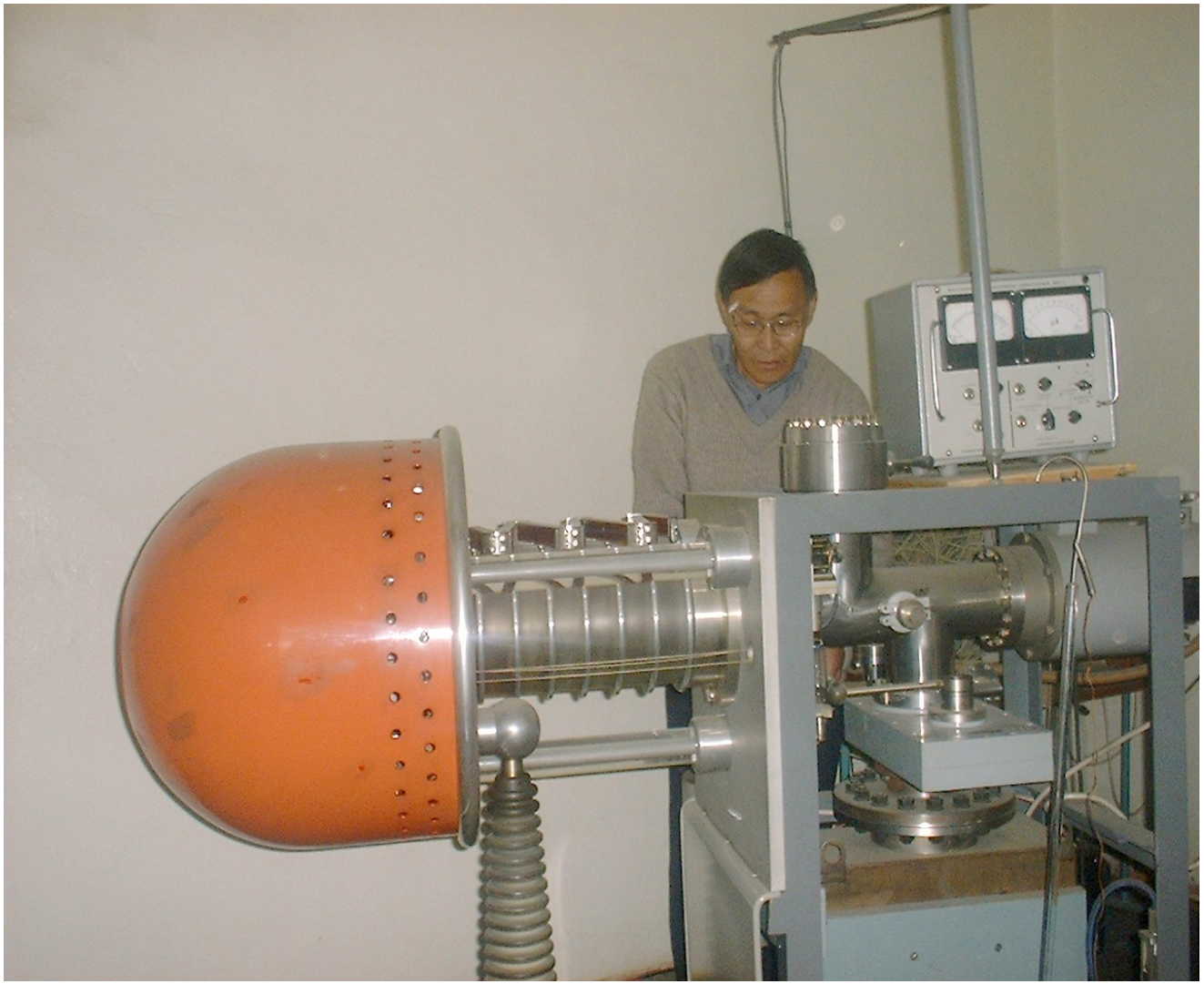
TERRITORY: 1 500 000 km², POPULATION: 2 500 000

ULAANBAATAR is Capital of Mongolia

Inhabitants - 1 300 000

National University of Mongolia
1942

NUCLEAR RESEARCH CENTER
NEUTRON GENERATOR



E=14MeV

$$F = 10^{10} s^{-1}$$

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^{252}Cf-NEUTRON SOURCE

$$F = 10^{9}\, n/s$$

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MICROTRON MT-22

$$E_e^{max} = 22 MeV$$

$$I_e = 20 \mu A$$

$$Y_\gamma = 10^{13} \gamma / s$$

$$F_n = 10^8 n / cm^2 s$$

NUCLEAR RESEARCH CENTER
CRYOGENIC INSTALLATION

$$T = -196^{0}C$$

$$productivity = 8\frac{l}{h}$$

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TOTAL REFLECTION X-RAY SPECTROMETER

$$resolution = 180eV$$

$$at 5.9 KeV$$

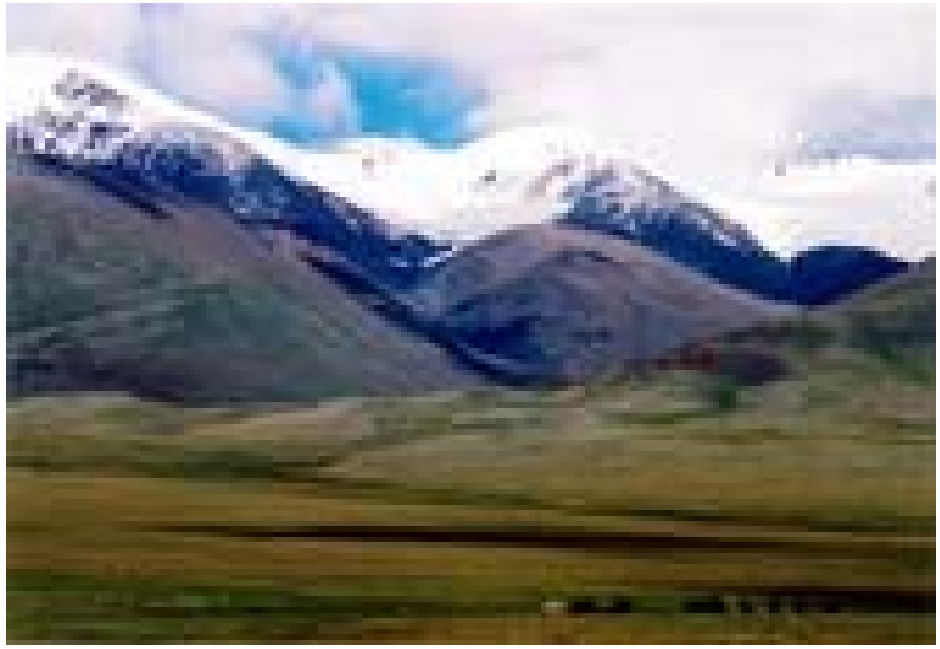
$$sensitivity = 10 - 100 \frac{\mu g}{l}$$

NUCLEAR RESEARCH CENTER
X-RAY SPECTROMETER

$$resolution = 185eV$$

$$sensitivity = 1 - 15\%$$

NUCLEAR RESEARCH CENTER
RADIOCHEMICAL LABORATORY

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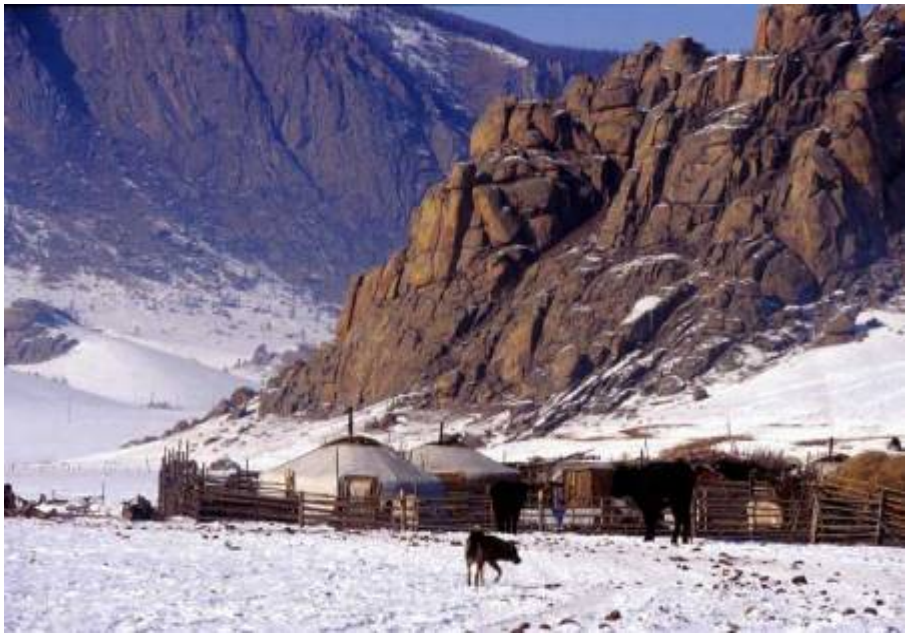
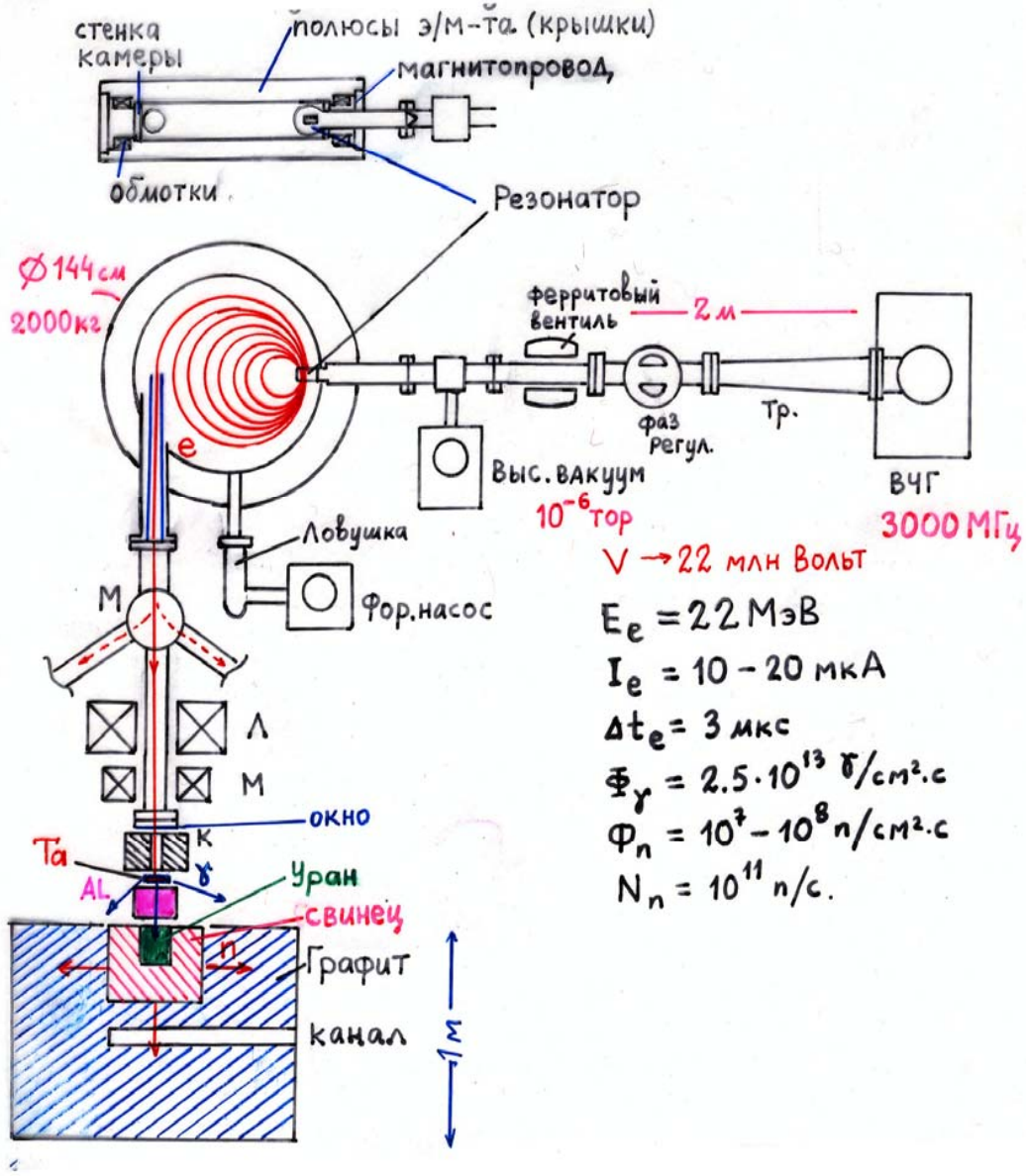


III MICROTRON MT-22



$V \to 22$ млн Вольт

$E_e = 22$ МэВ

$I_e = 10 - 20$ мкА

$\Delta t_e = 3$ мкс

$\Phi_\gamma = 2.5 \cdot 10^{13}$ γ/см²·с

$\Phi_n = 10^7 - 10^8$ n/см²·с

$N_n = 10^{11}$ n/с.