Electron screening in Al and Ni metals

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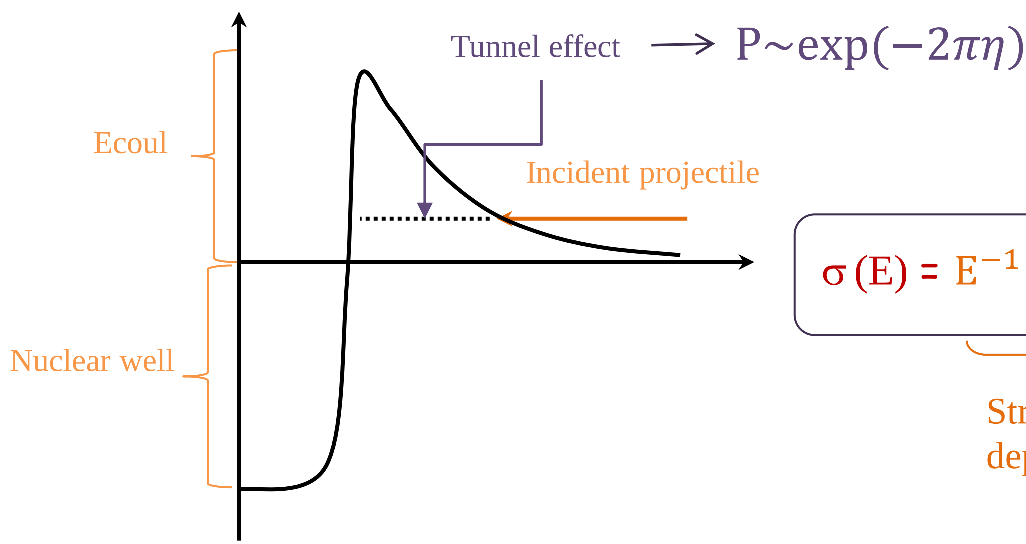
Sixth European Summer School on Experimental Nuclear Astrophysics

St. Tecla, Sicily 18-27. September

Due to Coulomb repulsion the cross section σ for charged particle induced nuclear reactions drops rapidly with decreasing beam energy.

As long as the energy available in the center of mass system is much smaller than the Coulomb barrier, reactions are possible only because of the tunneling effect.



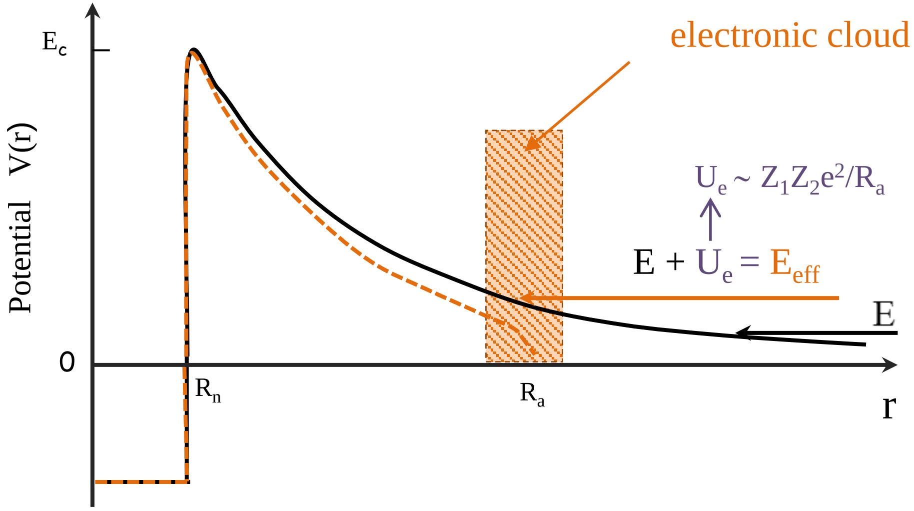
$$\sigma(E) = E^{-1} \exp(-2\pi\eta)\, S(E)$$

Strong energy dependence

Astrophysical S factor

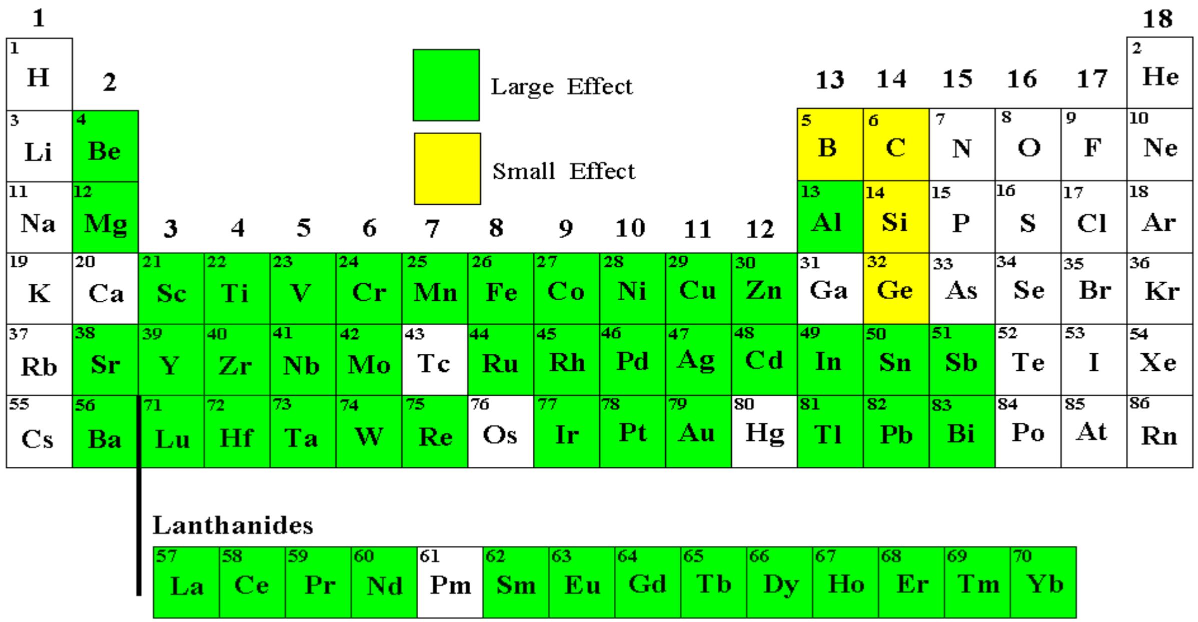
The cross section of charged particle-induced nuclear reactions is enhanced at subcoulomb energies by electron clouds surrounding the interacting nuclides.

The electron clouds act as a screening potential: the projectile effectively sees a reduced Coulomb barrier.



$$f_{lab} = \frac{\sigma_s(E)}{\sigma_b(E)} = \frac{\sigma_b(E+U_e)}{\sigma_b(E)}$$

d(d,p)t reaction was studied for deuterated metals, insulators and semiconductors [1], [2].



[1] C. Rolfs, Prog. Theor. Phys. Supl. **154,** 373 (2004).
[2] F. Raiola et al., J. Phys. G **31,** 1141-1149 (2005).

Electron screening in $^{7}Li(p,\alpha)\alpha$ and $^{6}Li(p,\alpha)^{3}He$ for different environments ☆

LUNA Collaboration

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The electron screening in the $^{7}Li(p,\alpha)\alpha$ reaction has been studied [3] at E_p=30 to 100 keV for different environments: Li_2WO_4 insulator, Li metal and PdLi alloys.

For the insulator a screening potential energy of U_e=185±150 eV was observed, consistent with adiabatic limit.

For the Li metal and the PdLi alloys large values of U_e=1280±60 eV and 3790 ±330 eV were observed.

Debye model scaling $U_e \sim Z_t$ (charge number of target).

[3] J. Cruz et al., Phys. Lett. B **624,** 181 **(**2005).

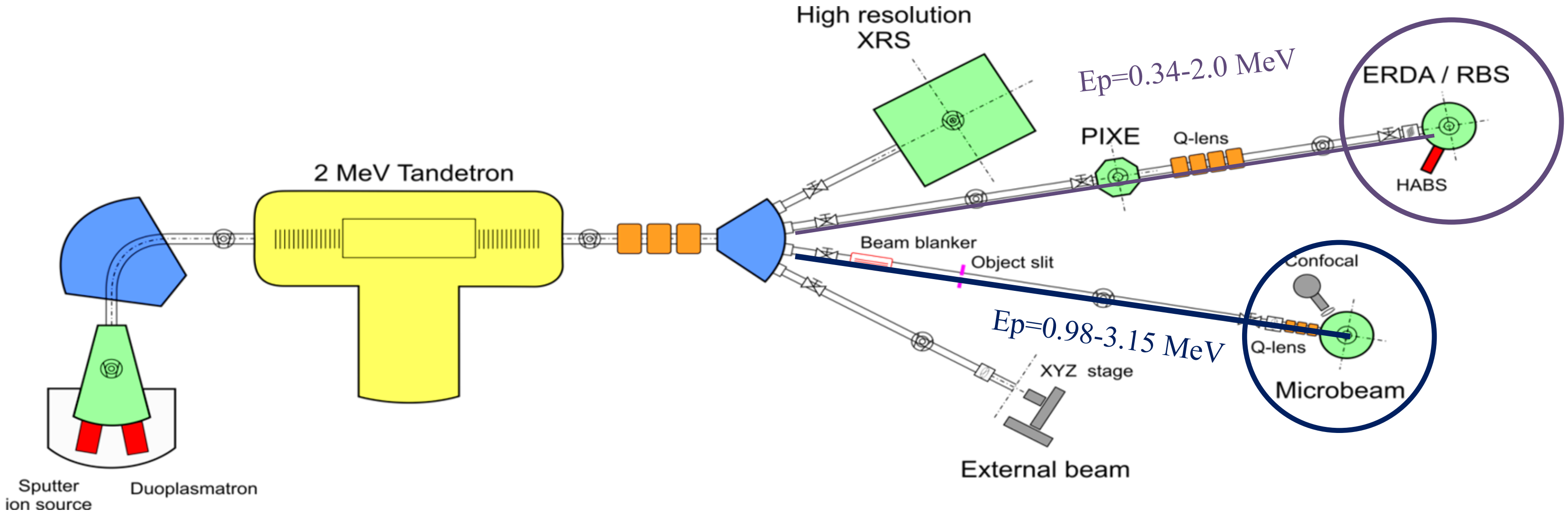
Experiments

ERDA/RBS line: ^{7}Li beams with energies between 0.34 and 2.0 MeV

Targets: H loaded Pd metal and $Pd_{77}Ag_{23}$ alloy

Microbeam line: proton energy: 0.98-3.15 MeV

Targets: Ni and Al metals, PdNi alloy and Al_2O_3 and NiO insulators

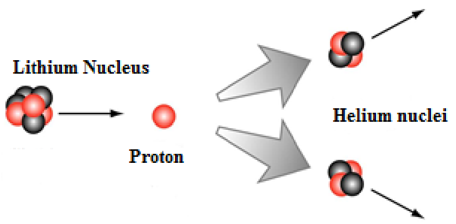


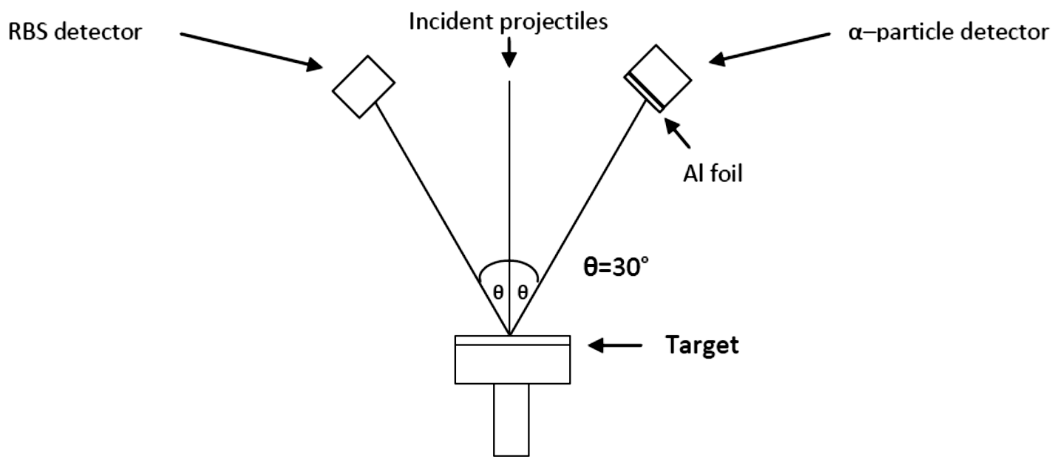
Experiment at ERDA/RBS line

Electron screening was studied in the reaction $^{1}H(^{7}Li,\alpha)^{4}He$.

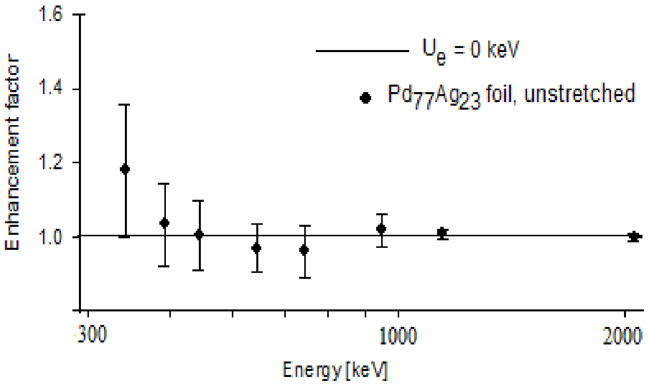
Hydrogen was absorbed into the metal from gas phase.

Hydrogen concentrations were determined by ERDA measurements.





Results

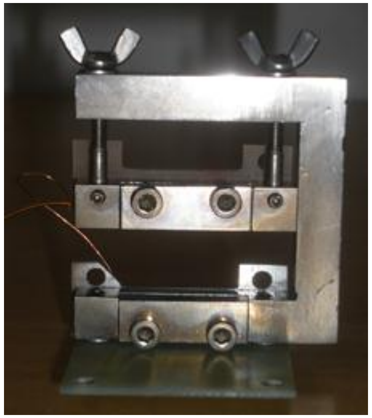


U_e<0.4 keV was obtained for the unstretched $Pd_{77}Ag_{23}$ foil.

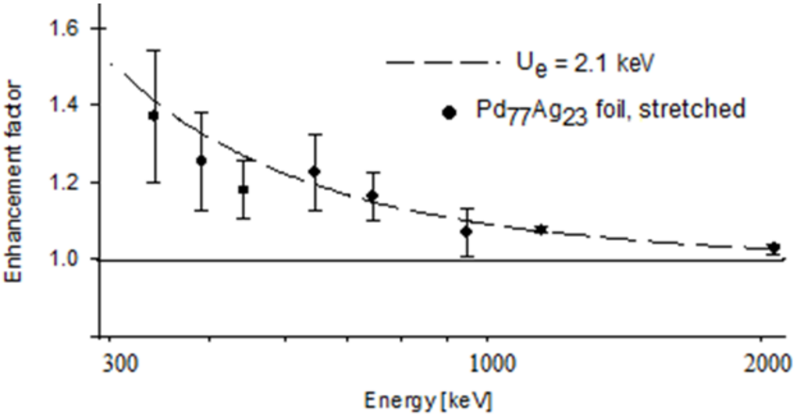
This is consistent with adiabatic screening limit and with the measurement in ref. [3] for the insulator Li_2WO_4 where U_e=0.180±0.150 keV was measured.

We observed that the count rates of α particles increased when the metallic foils were put under tensile stress, either from deformation caused by hydrogen loading or from mechanical stretching.

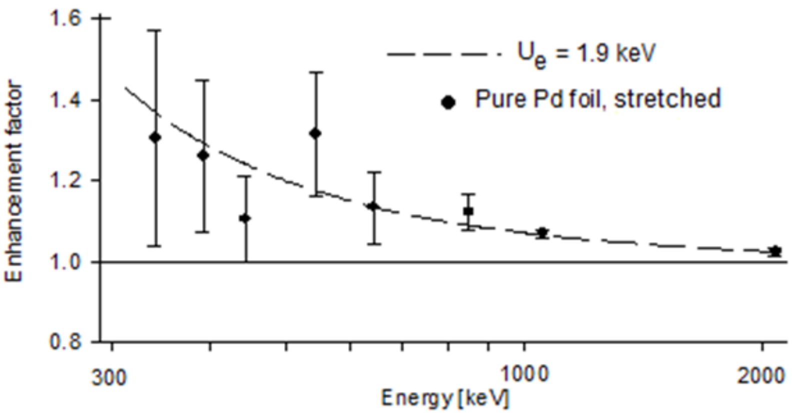
The hydrogen loaded Pd and $Pd_{77}Ag_{23}$ foils were clamped to the frame along two opposite edges. The frame was then extended along the free edges of the foil with two screws.



[3] J. Cruz et al., Phys. Lett. B **624,** 181 **(**2005).



The stretched $Pd_{77}Ag_{23}$ foil exhibited a large screening effect at U_e=2.1±0.2 keV.

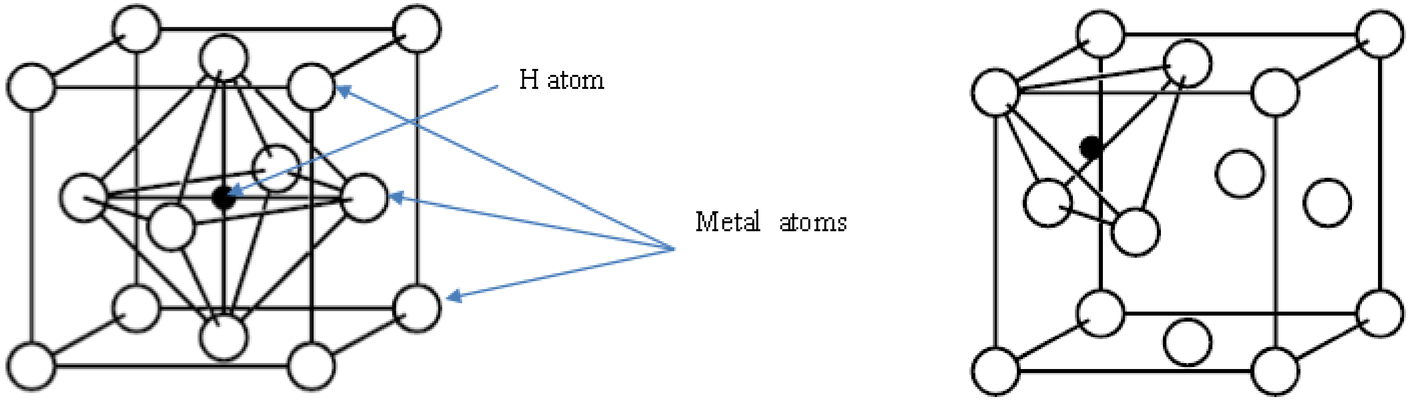


The stretched pure Pd foil exhibited also large screening effect at U_e=1.9±0.2 keV.

The measured yields in unstretched $Pd_{77}Ag_{23}$ foil can be well described with calculations for bare nuclei. The screening potential energy in this target is too small to be statistically different from zero by our measurements.

The fitted U_e values for the stretched $Pd_{77}Ag_{23}$ and Pd foils could be compared to U_e=3.8±0.3 keV [3] measured for the same reaction in normal kinematics. In the latter experiment lithium was implanted into the $Pd_{99}Li_1$ alloy by plasma discharge.

Possible explanation

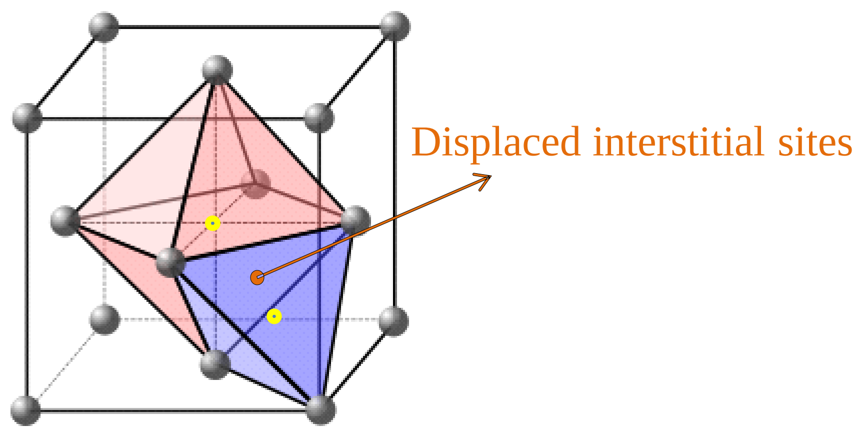


Octahedral (left) and tetrahedral (right) interstitial sites in the fcc lattice

[3] J. Cruz et al., Phys. Lett. B **624,** 181 **(**2005)

We explain large electron screening by the migration of protons from ordinary octahedral interstitial positions to displaced octahedral (dis-O) sites.

The movement of protons is caused by the stress, either mechanical or the one from radiation damage due to ion implantation.



High-*Z* electron screening: the cases $^{50}V(p,n)^{50}Cr$ and $^{176}Lu(p,n)^{176}Hf$

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[2] Institut für Physik mit Ionenstrahlen, Ruhr-Universität Bochum, Bochum, Germany

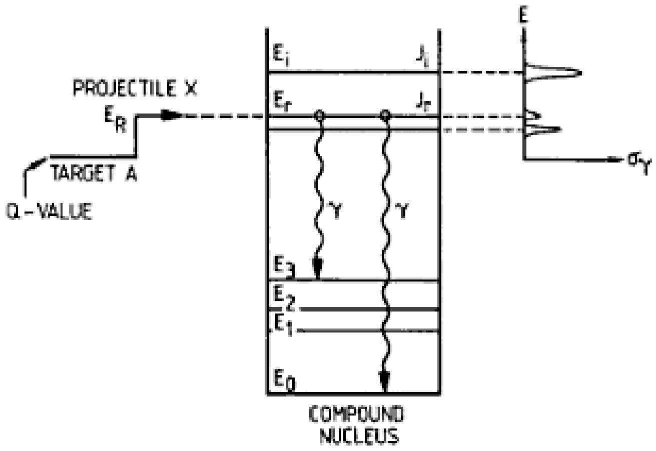
The electron screening in $^{50}V(p,n)^{50}Cr$ reaction has been studied [4] at Ep = 0.75 to 1.55 MeV for different environments: VO_2 insulator, V metal and $PdV_{10\%}$ alloy.

Relative to the insulator metal and alloy showed a large screening energy of $U_e = 27 \pm 9$ and 34 ± 11 keV, respectively.

$^{176}Lu(p,n)^{176}Hf$ was also studied at similar proton energies for a Lu_2O_3 insulator, a Lu metal and a $PdLu_{10\%}$ alloy; there a narrow resonance at $E_{pr} = 0.81$ MeV exhibiting a shift in proton resonance energy of $U_e = 32 \pm 2$ and 33 ± 2 keV for the metal and alloy, respectively, relative to the insulator was observed.

[4] K. U. Kettner et al., J. Phys. G **32,** 489 (2006).

When the bombarding energy *E* in the entrance channel is close to the energy *E* for exciting a state in the compound nucleus the cross section for the reaction takes a form of a Lorentz distribution – Resonant reaction.



$$Q+E_R=E_r$$

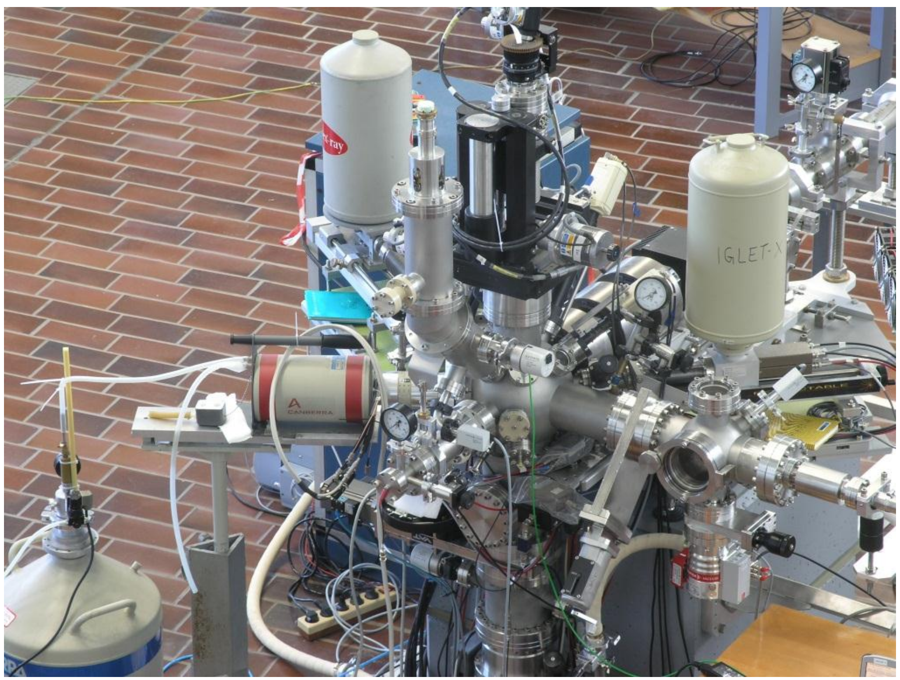
Resonant capture reaction A(x,γ)B [5]

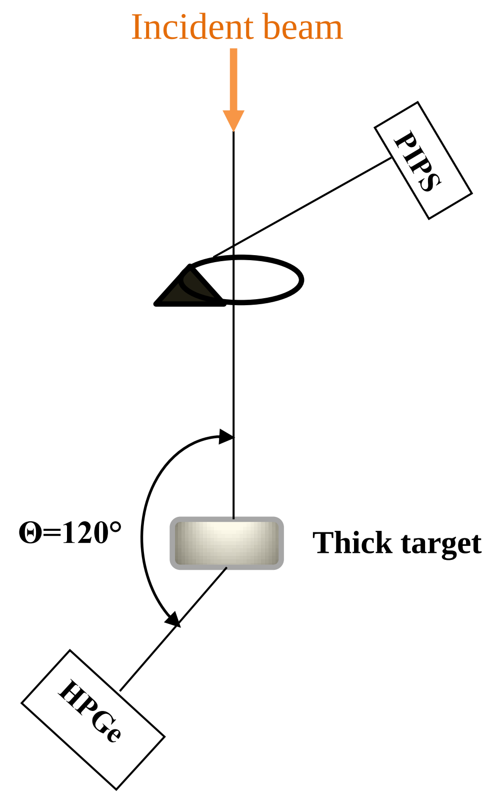
[5] C. E. Rolfs, W. S. Rodney, Cauldrons in the Cosmos, The University of Chicago press, Chicago and London 1988.

Experiment at Microbeam line

The measurements were based on observation of the thick target yields of $^{59,61,63,64,65}Cu$, $^{58,60,62}Ni$ and ^{28}Si de-excitations γ rays.

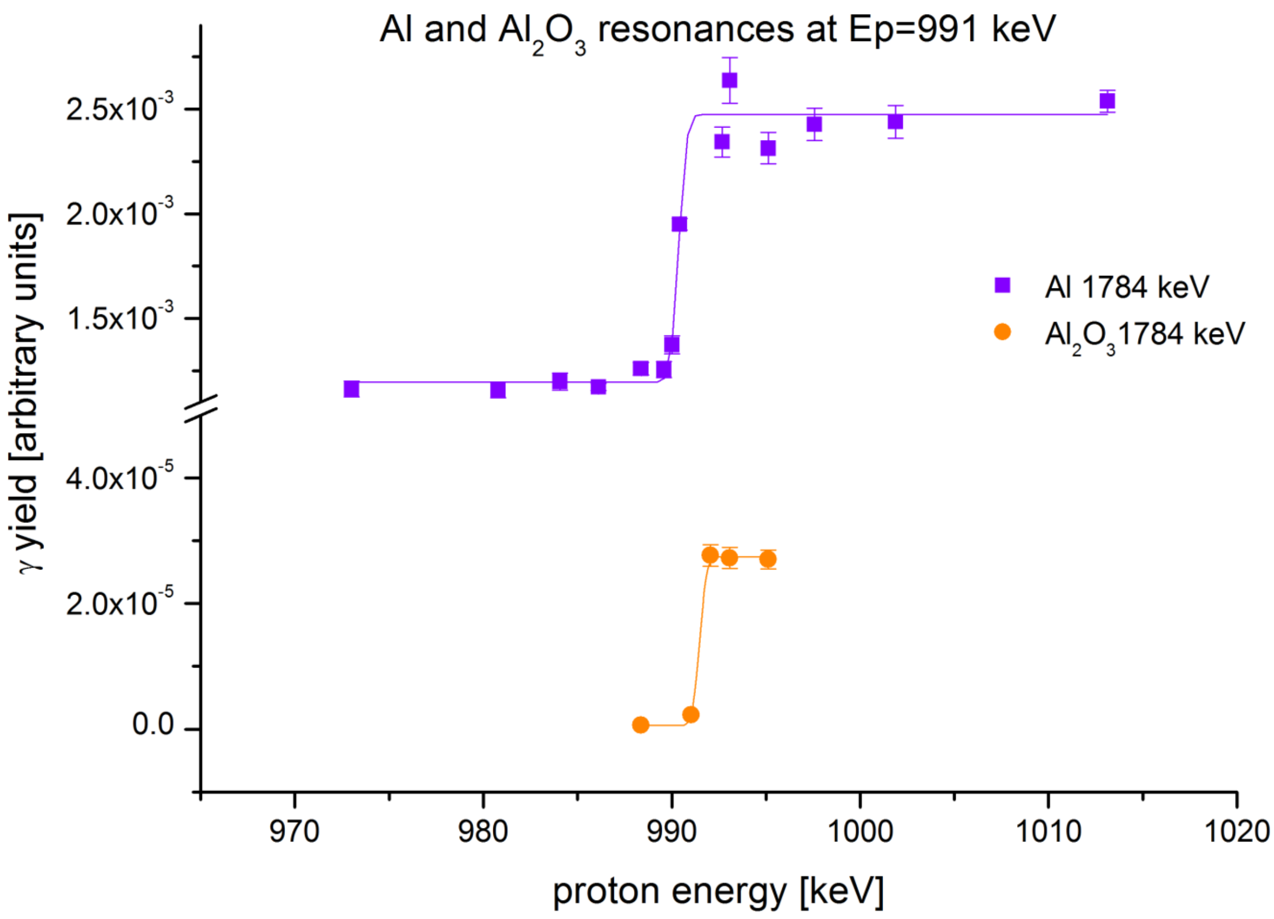
Proton dose is inferred from the peak area in the RBS spectrum pertaining to protons which are backscattered from chopper.



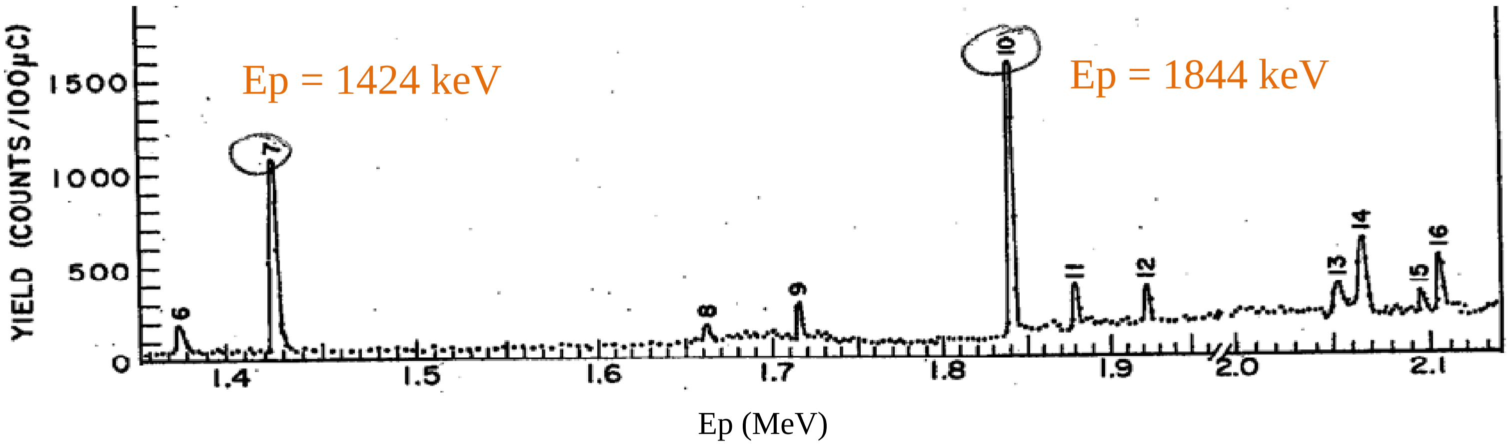


Results

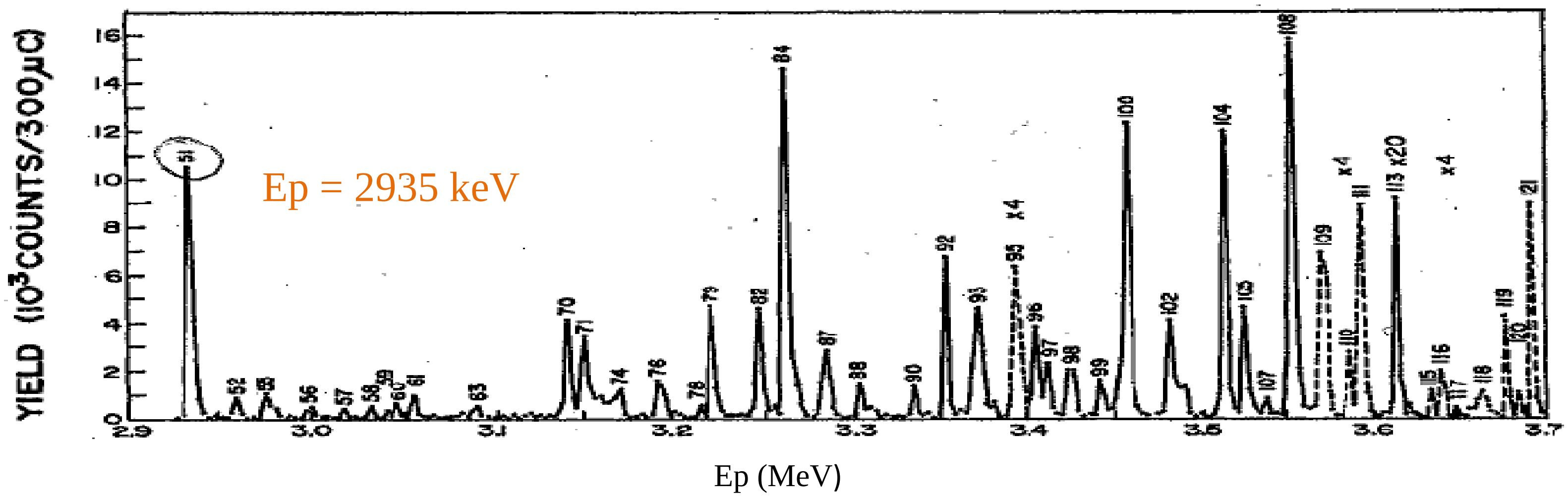
$^{28}Al(p,\gamma)^{29}Si$



$^{58}Ni(p,\gamma)^{59}Cu$

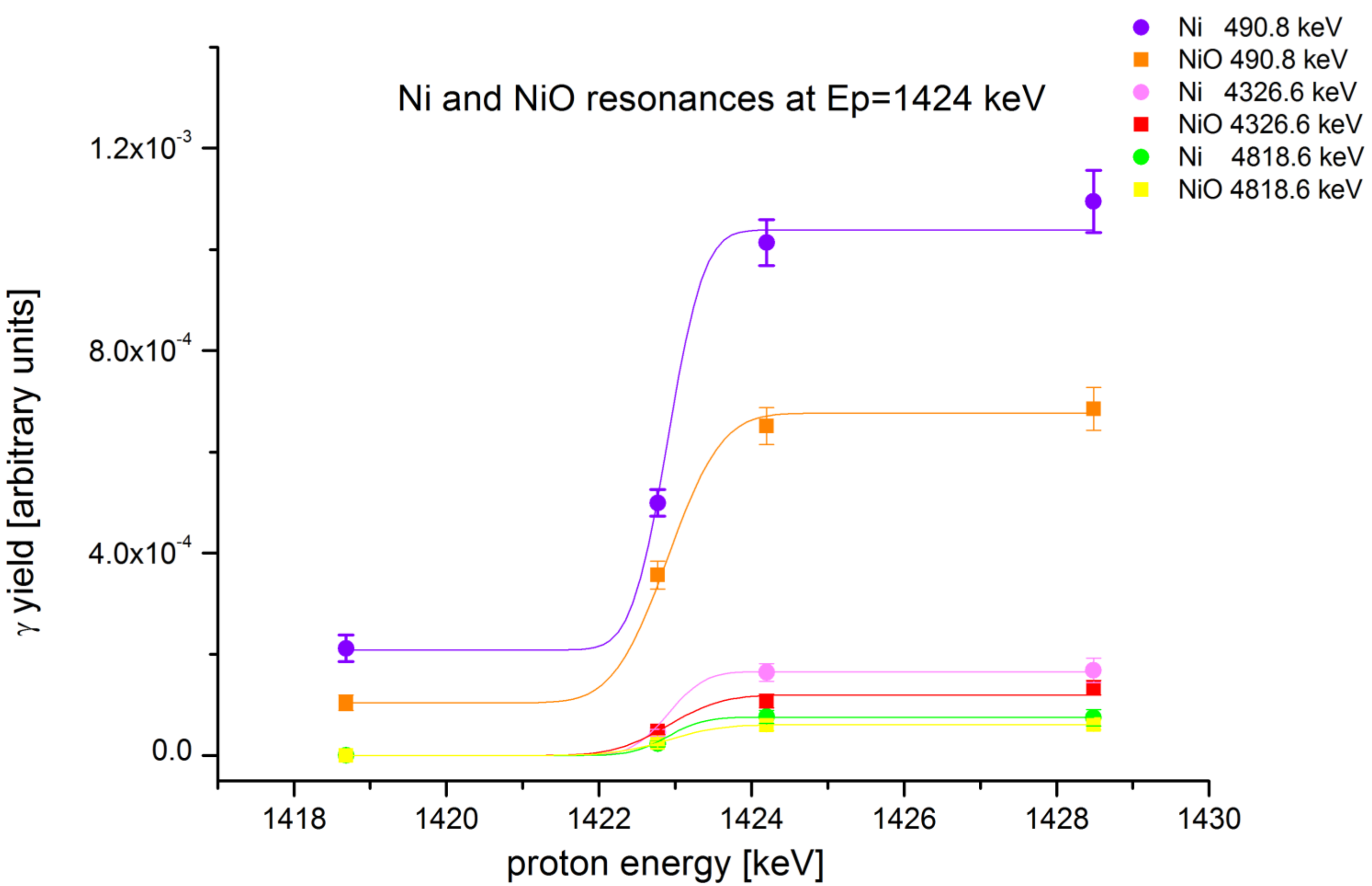


$^{58}Ni(p,p'\gamma)^{58}Ni$

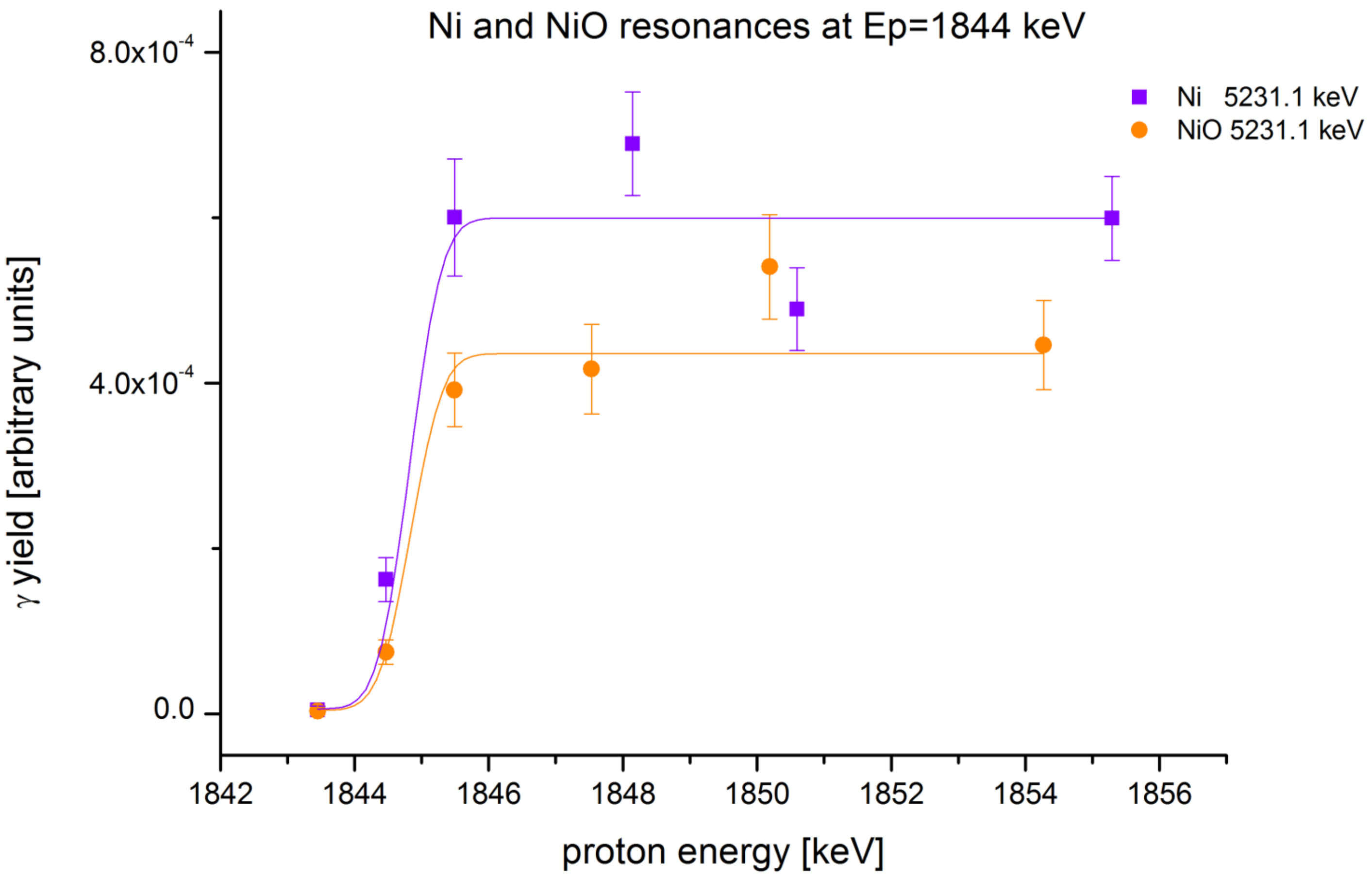


[6] G. U. Din et. al, Phys. Rev. C., **31** (1985) 800.

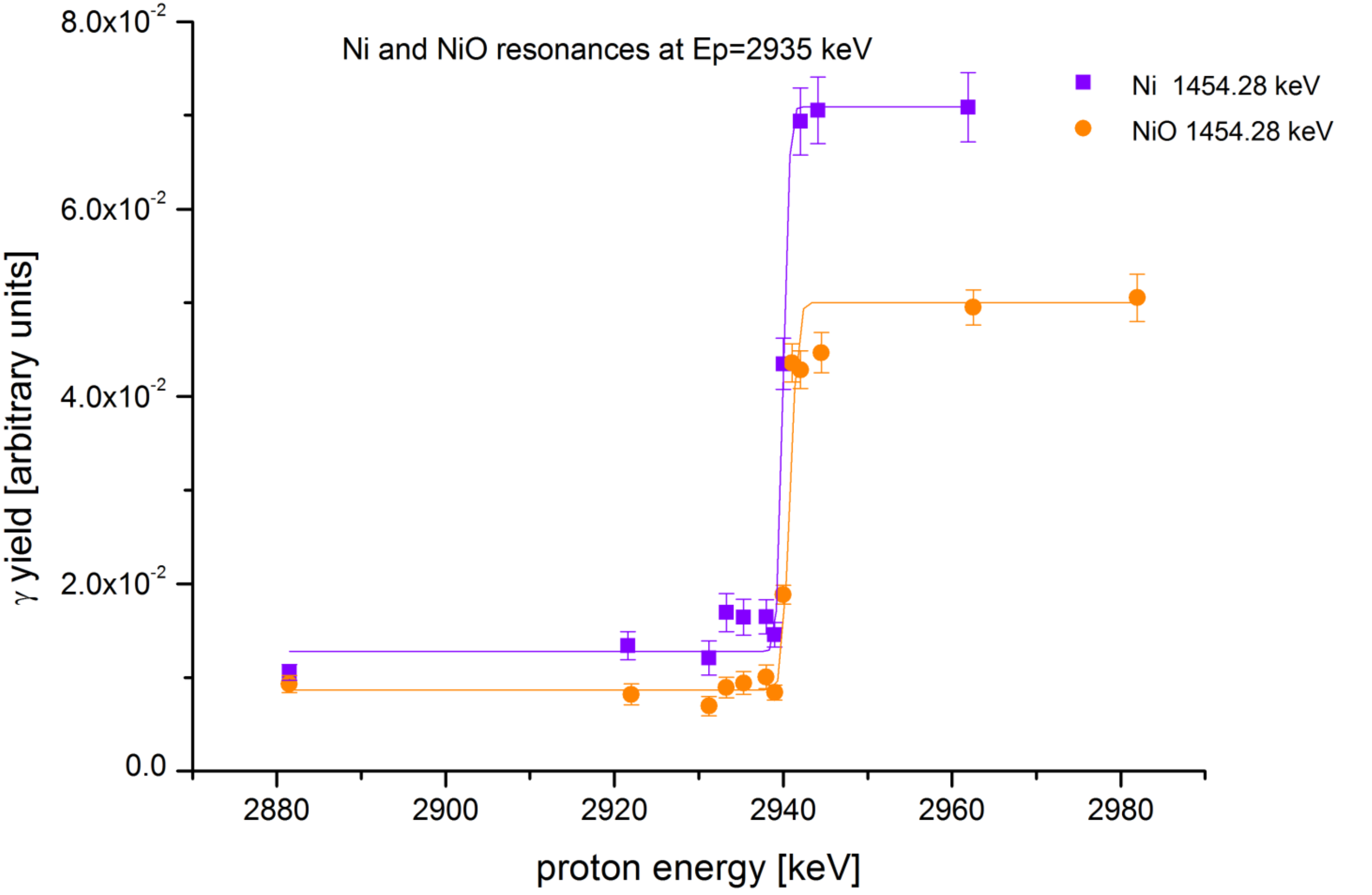
$^{58}Ni(p,\gamma)^{59}Cu$



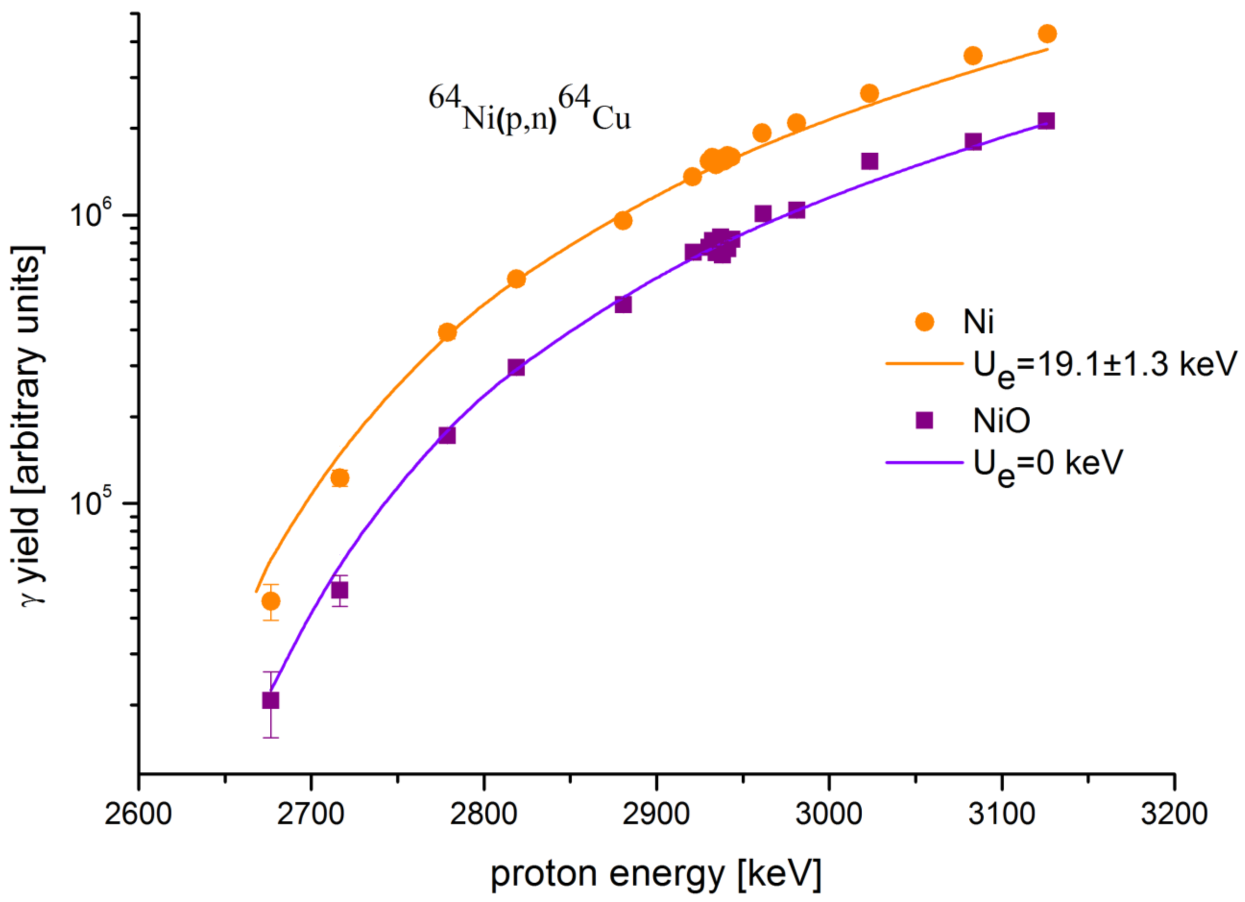
$^{58}Ni(p,\gamma)^{59}Cu$



^{58}Ni(p,p'γ)^{58}Ni



$^{64}Ni(p,n)^{64}Cu$, Eγ=159.28 keV



Conclusions

Shifts in resonance energy for the metallic target relative to the insulator ones were not observed, furthermore the values were the same within experimental errors of about 2 keV. Also the resonance strengths were the same in Ni and NiO.

Very preliminary results show that large electron screening might be observed only in the $^{64}Ni(p,n)^{64}Cu$ reaction, where U_e=19.1±1.3 keV was measured from the intensity of the 159.28 keV γ ray.

Thank you for your attention