α-induced cross-section measurements on p-nuclei

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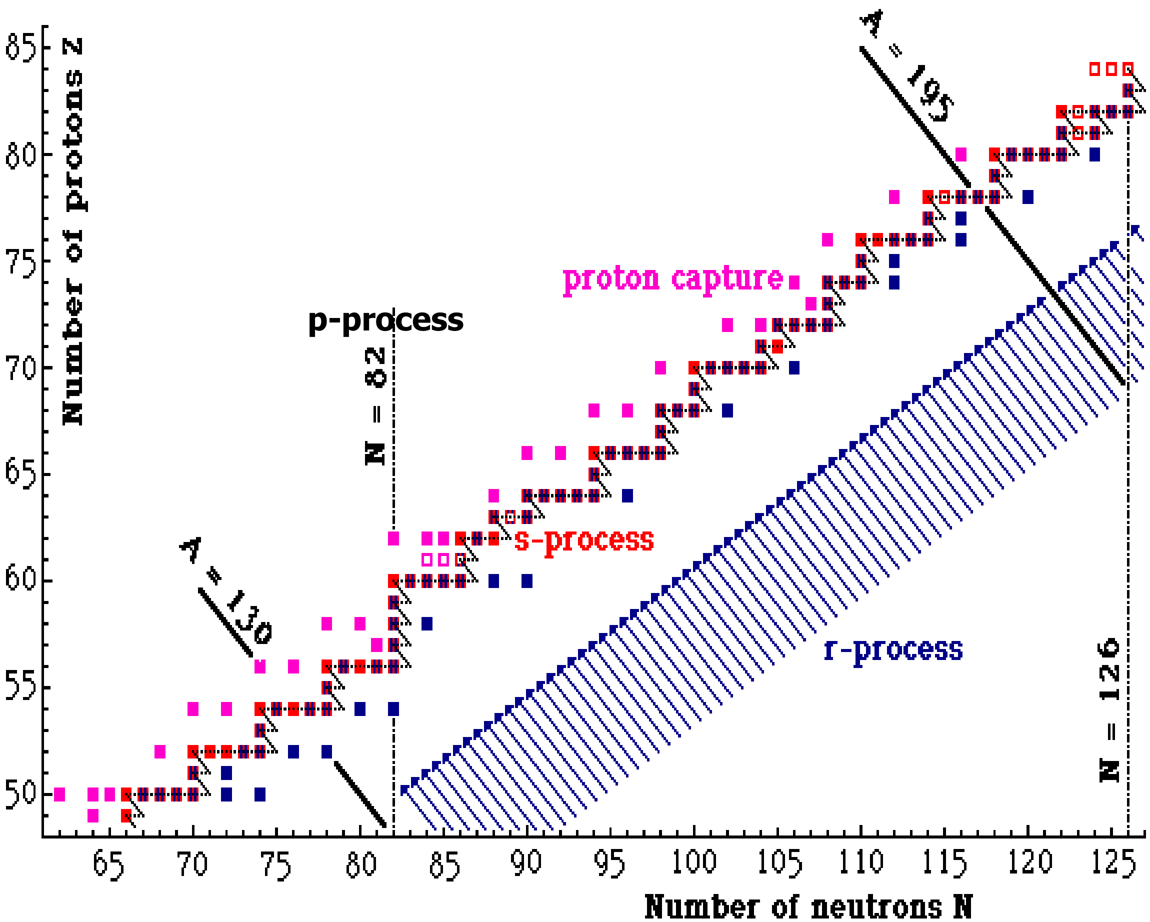
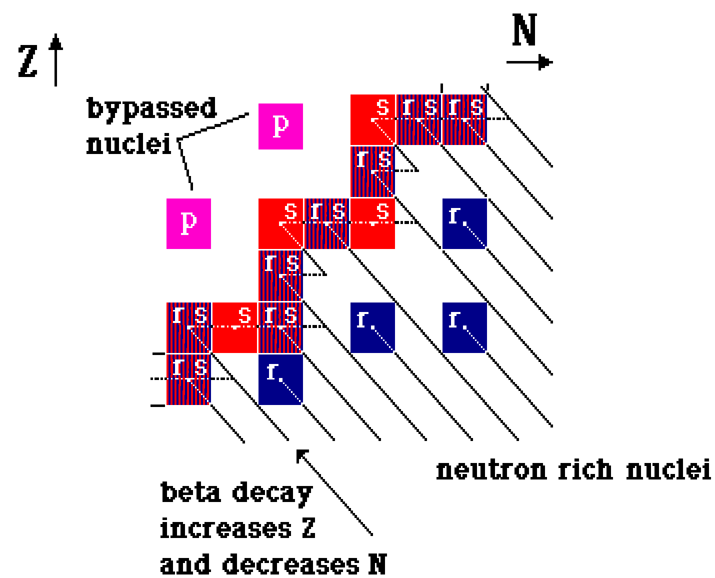
Outline

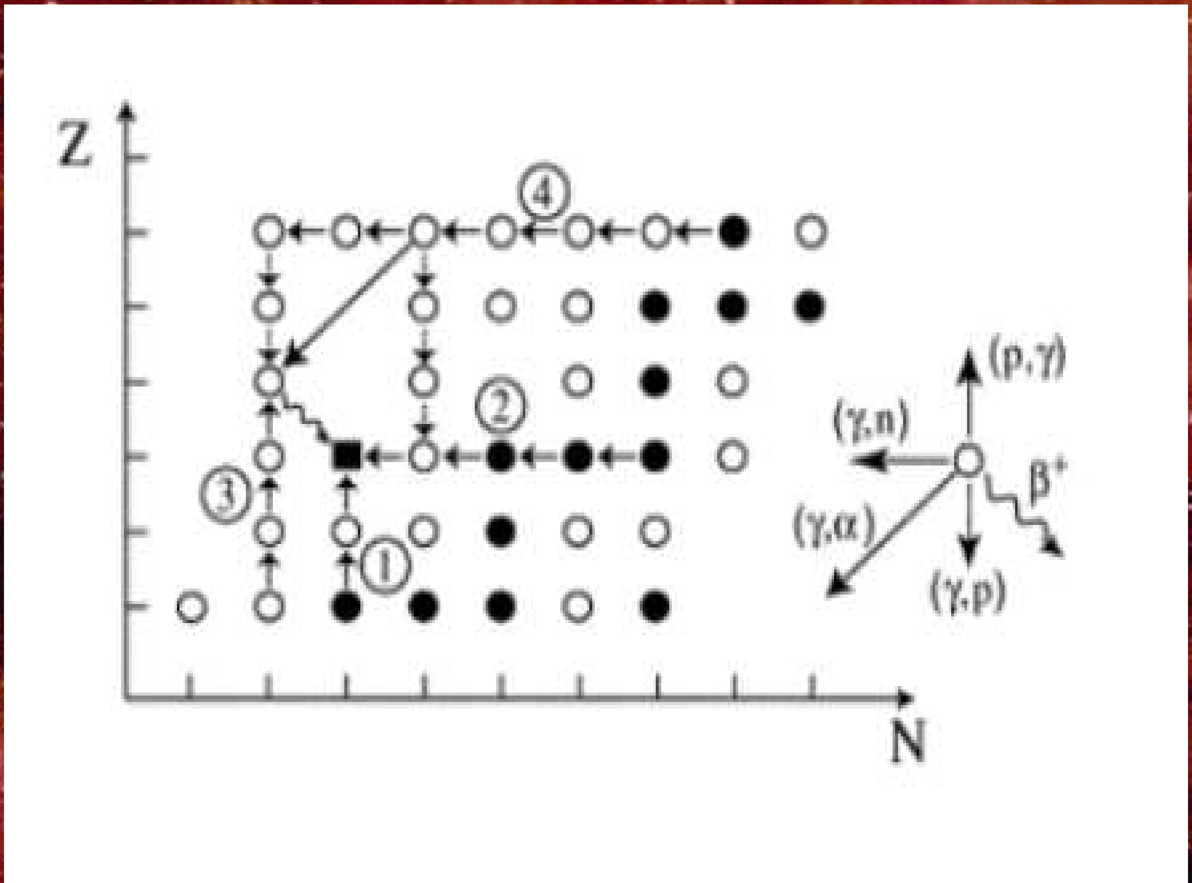
- P-Process overview
- Status of (α,γ) experiments
- $^{106}Cd(\alpha,\gamma)^{110}Sn$ and $^{112}Sn(\alpha,\gamma)^{116}Te$
- The two experiments
- The results
- Conclusion

Nucleosynthesis





P-nuclei production



black dots: s- or r- nuclides

black square: p-nuclides

open dots: unstable nuclei

P-process sites

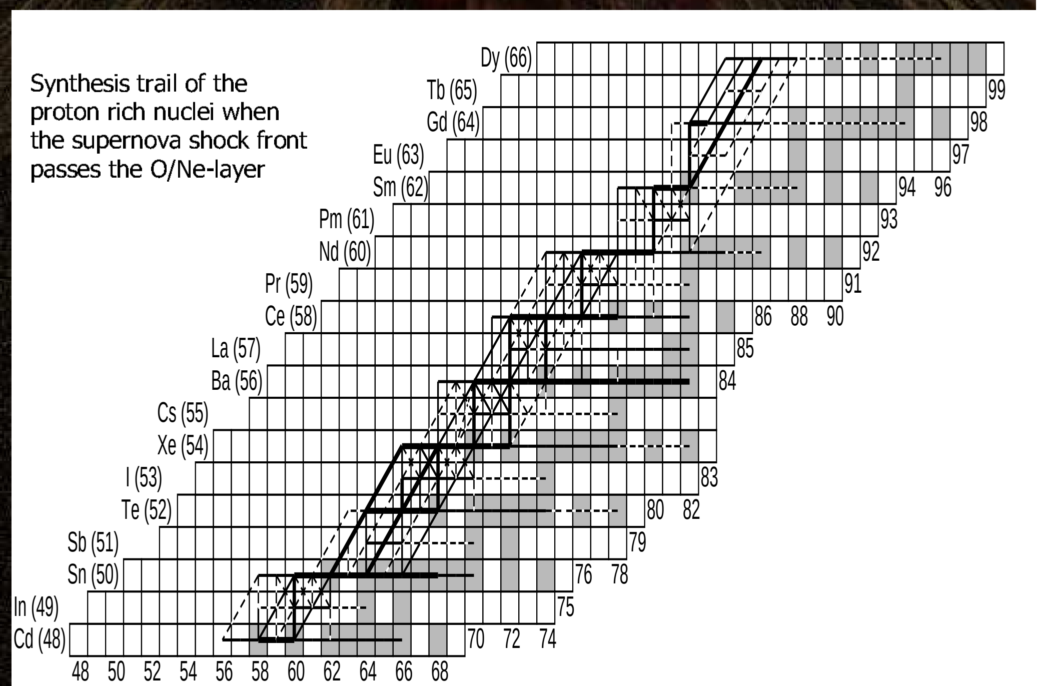
In order for P-process nuclei to form:

a. Abundant enough seed nuclei

b. High enough temperatures (T_9 = 2-3)

c. Short time scales (for freeze out)

These conditions are best met in the Ne-O layer of Type II Supernova



Motivation

Abundance calculations for the p-nuclei involve an extended network of about 20,000 nuclear reactions of almost 2000 nuclei with masses ranging from 12 to 210.

The cross sections used to calculate the astrophysical reaction rates in network studies are based on the Hauser-Feshbach statistical model

α-optical potentials are needed to calculate the transmission probability of the α particle through the Coulomb barrier of the nucleus

These cross sections are sensitive to the choice of α-nucleus potential (as shown in the case of $^{144}Sm(\alpha,\gamma)$…deviation)…..significant discrepancies have been observed between theory and experiment

To test the reliability of the HF calculations ….more (γ,α) data is needed

Nucleus	Anders and Grevesse [13]	Error (%)
^{74}Se ←	0.55	6.4
^{78}Kr	0.153	18
^{84}Sr	0.132	8.1
^{92}Mo	0.378	5.5
^{94}Mo	0.236	5.5
^{96}Ru ←	0.103	5.4
^{98}Ru	0.035	5.4
^{102}Pd	0.0142	6.6
^{106}Cd	0.0201	6.5
^{108}Cd	0.0143	6.5
^{113}In	0.0079	6.4
^{112}Sn ←	0.0372	9.4
^{114}Sn	0.0252	9.4
^{115}Sn	0.0129	9.4
^{120}Te	0.0043	10
^{124}Xe	0.00571	20
^{126}Xe	0.00509	20
^{130}Ba	0.00476	6.3
^{132}Ba	0.00453	6.3
^{138}La	0.000409	2
^{136}Ce	0.00216	1.7
^{138}Ce	0.00284	1.7
^{144}Sm ←	0.008	1.3
^{152}Gd	0.00066	1.4
^{156}Dy	0.000221	1.4
^{158}Dy	0.000378	1.4
^{162}Er	0.000351	1.3
^{164}Er	0.00404	1.3
^{168}Yb	0.000322	1.6
^{174}Hf	0.000249	1.9
^{180}Ta	2.48e-06	1.8
^{180}W	0.000173	5.1
^{184}Os	0.000122	6.3
^{190}Pt	0.00017	7.4
^{196}Hg	0.00048	12

$^{70}Ge(\alpha,\gamma)^{74}Se$

$^{96}Ru(\alpha,\gamma)^{100}Pd$

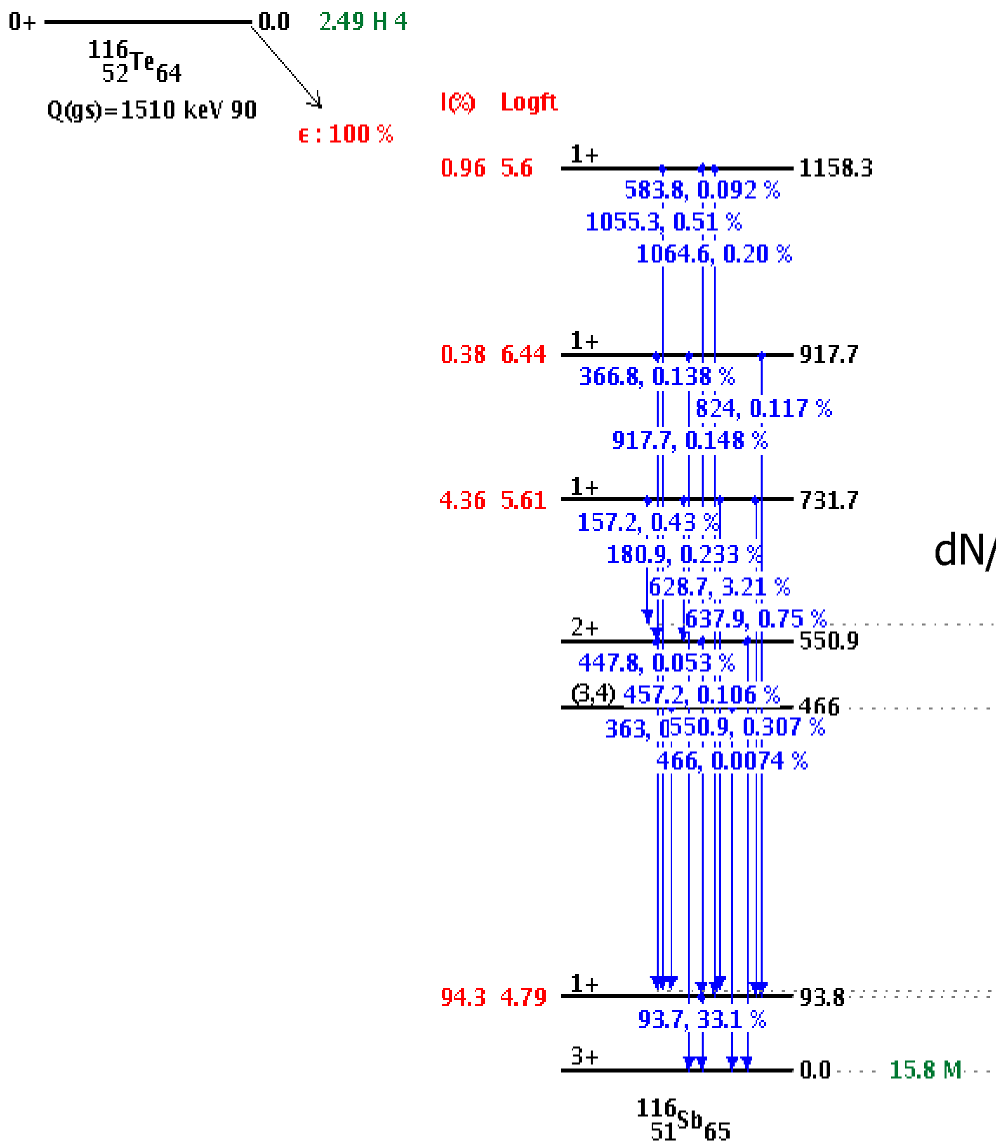
$^{112}Sn(\alpha,\gamma)^{116}Te$ (2 pts)

$^{144}Sm(\alpha,\gamma)^{148}Gd$

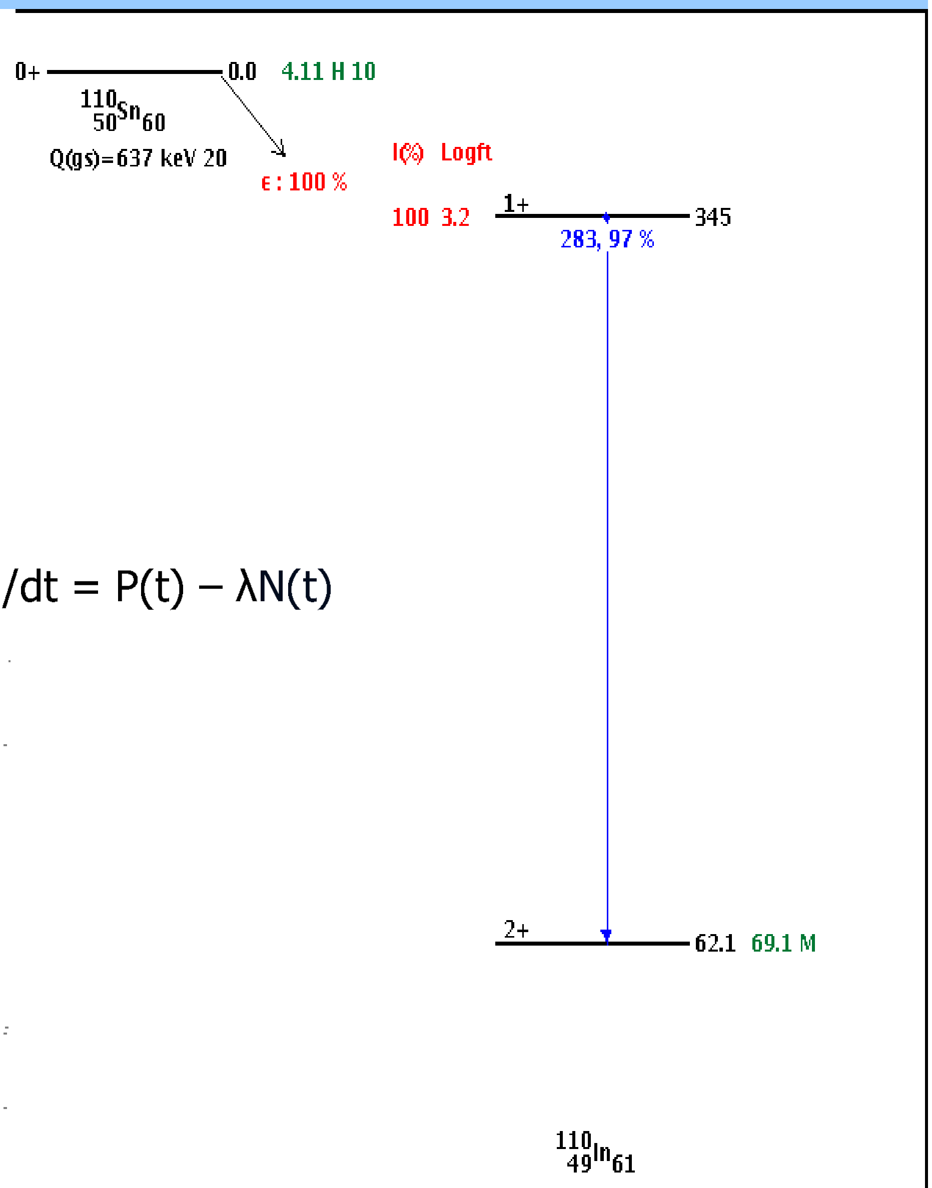
Activation Method

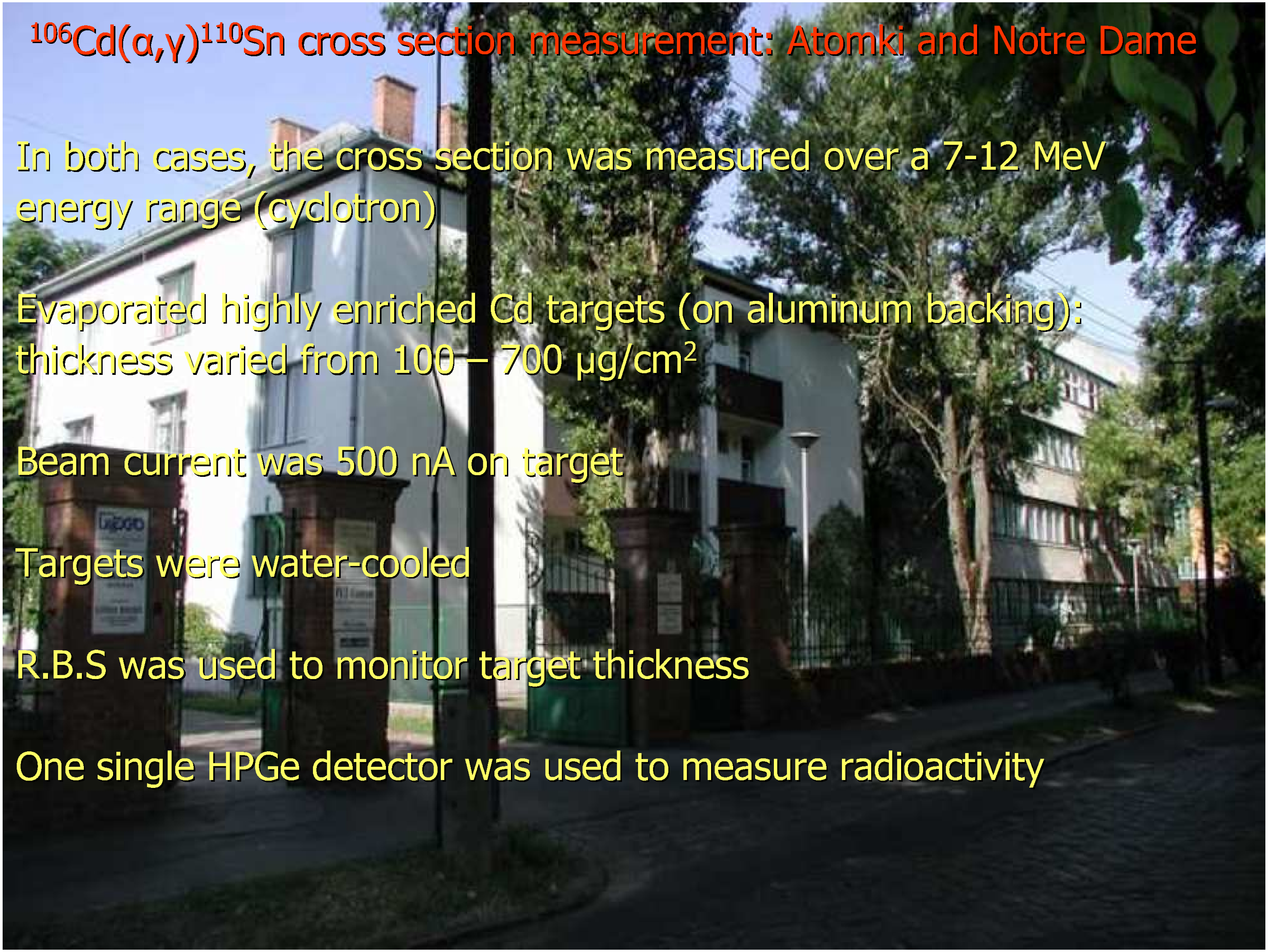
Irradiate a stable nucleus to produce a radioactive species:

$^{106}Cd(\alpha,\gamma)^{110}Sn$ $^{112}Sn(\alpha,\gamma)^{116}Te$



$$dN/dt = P(t) - \lambda N(t)$$





$^{106}Cd(\alpha,\gamma)^{110}Sn$ cross section measurement: Atomki and Notre Dame

In both cases, the cross section was measured over a 7-12 MeV energy range (cyclotron)

Evaporated highly enriched Cd targets (on aluminum backing): thickness varied from 100 – 700 μg/cm^2

Beam current was 500 nA on target

Targets were water-cooled

R.B.S was used to monitor target thickness

One single HPGe detector was used to measure radioactivity

Notre Dame Run

Our accelerator is a Van de Graaff (FN) tandem (Helium Ion source)

Our energy range was 7 to 12 MeV (in 0.5 MeV increments…Gamow window is from 7 to 11 MeV for both reactions)

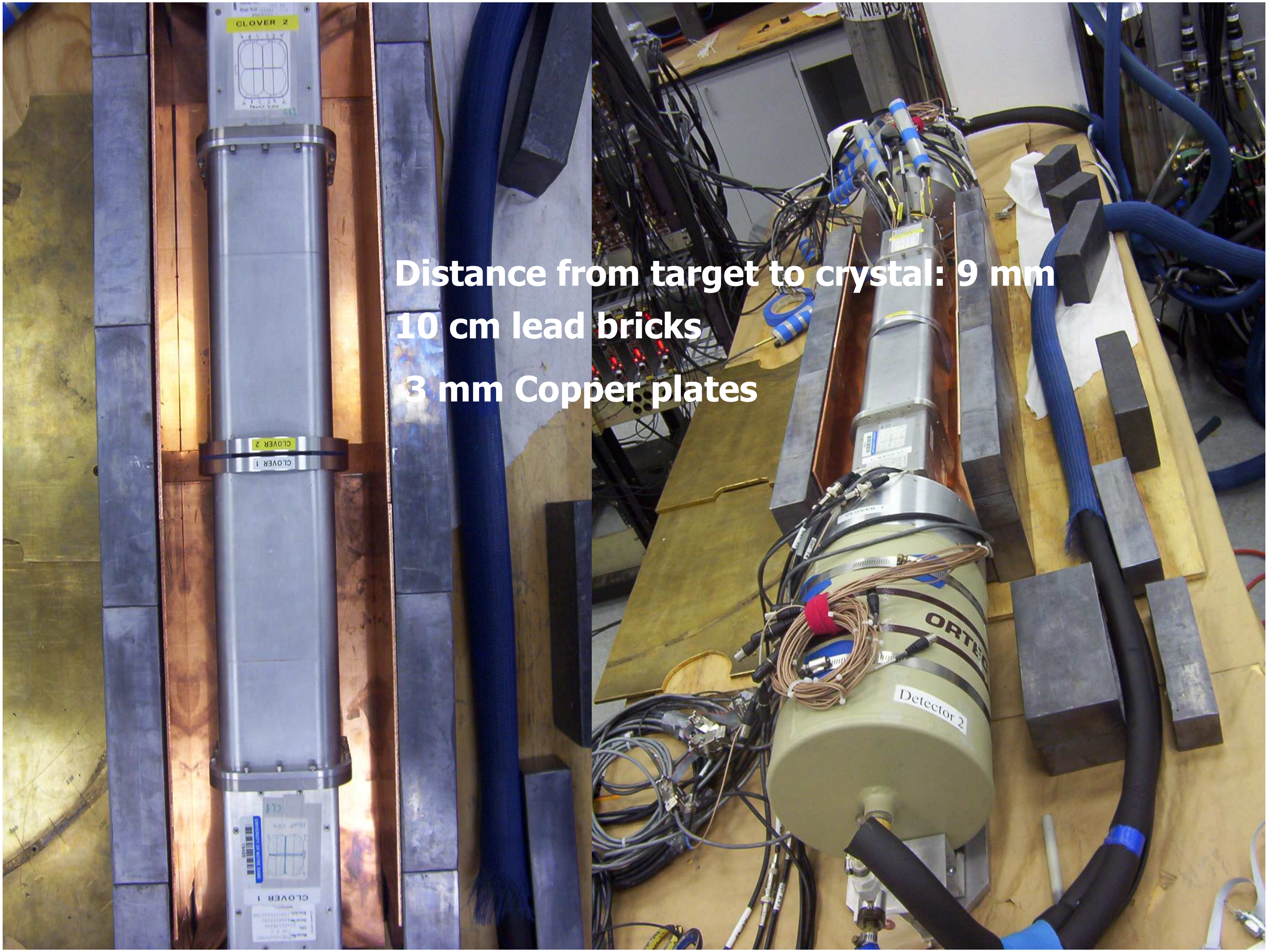
Our targets were on the order of 2 mg/cm^2 (highly enriched rolled Cd and Sn targets on a tantalum frame)

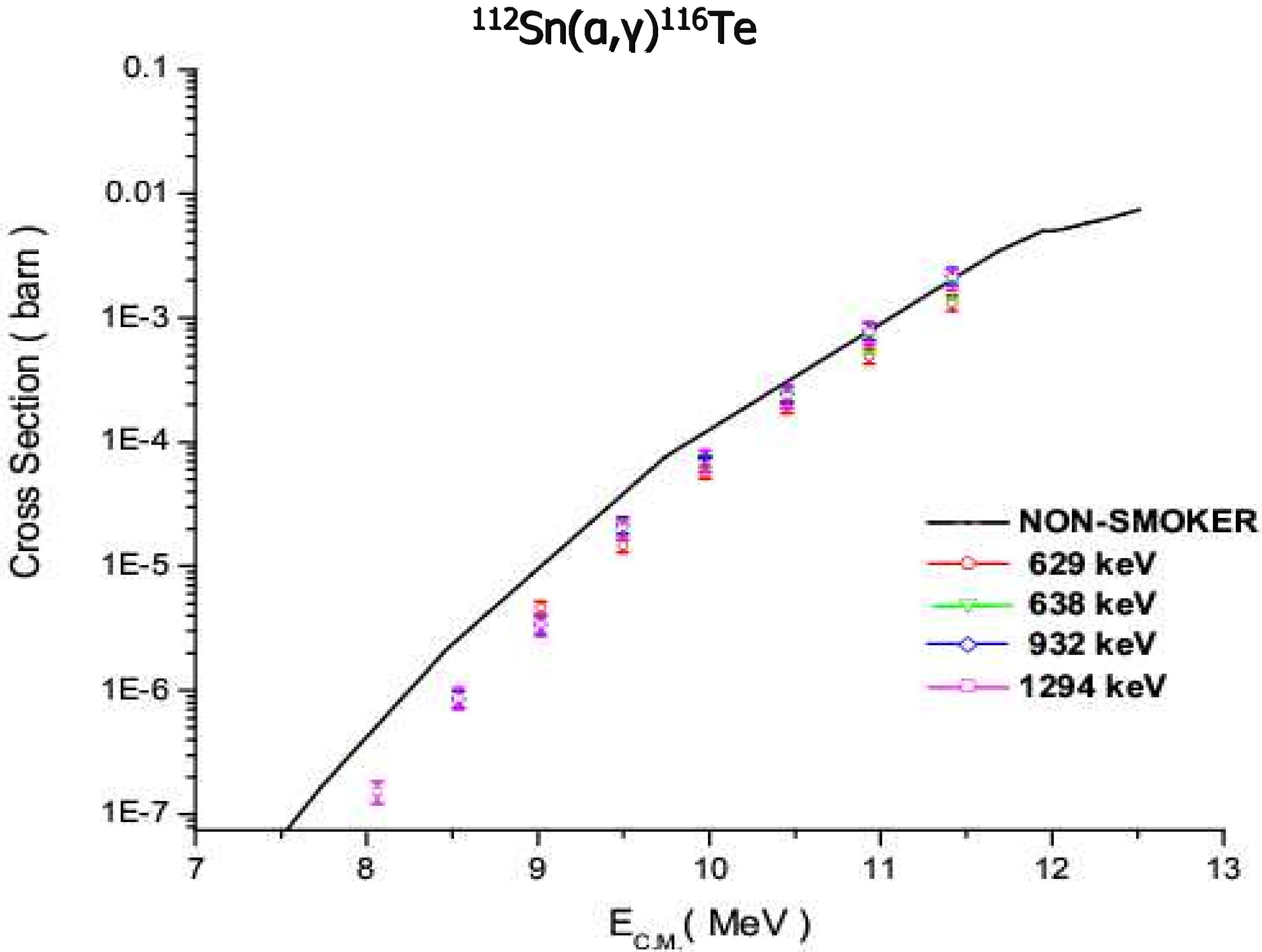
Beam current ranged from 90 to 290 nA (not to exceed 300 nA)

Targets were air-cooled

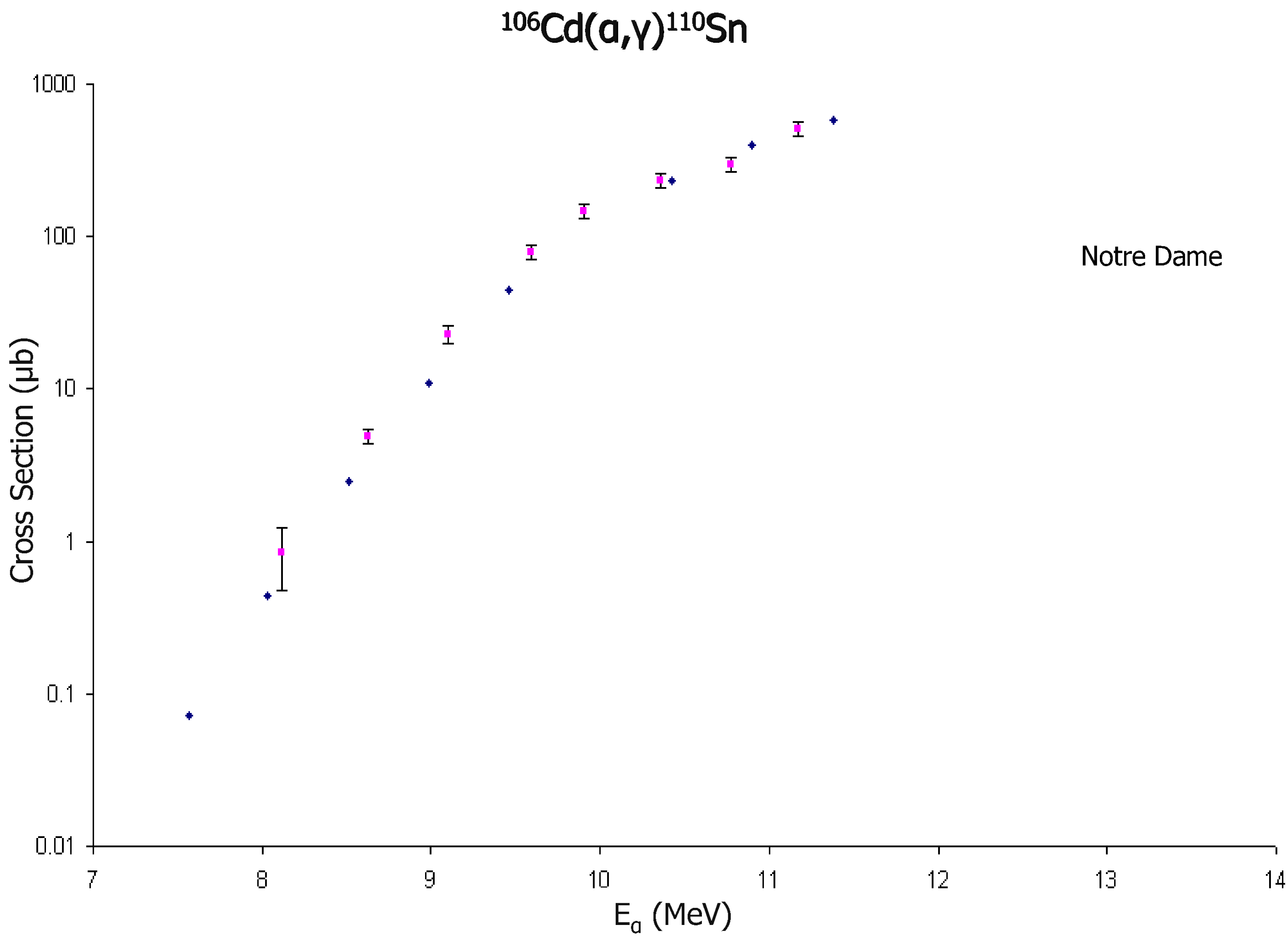
R.B.S. was used to monitor target thickness

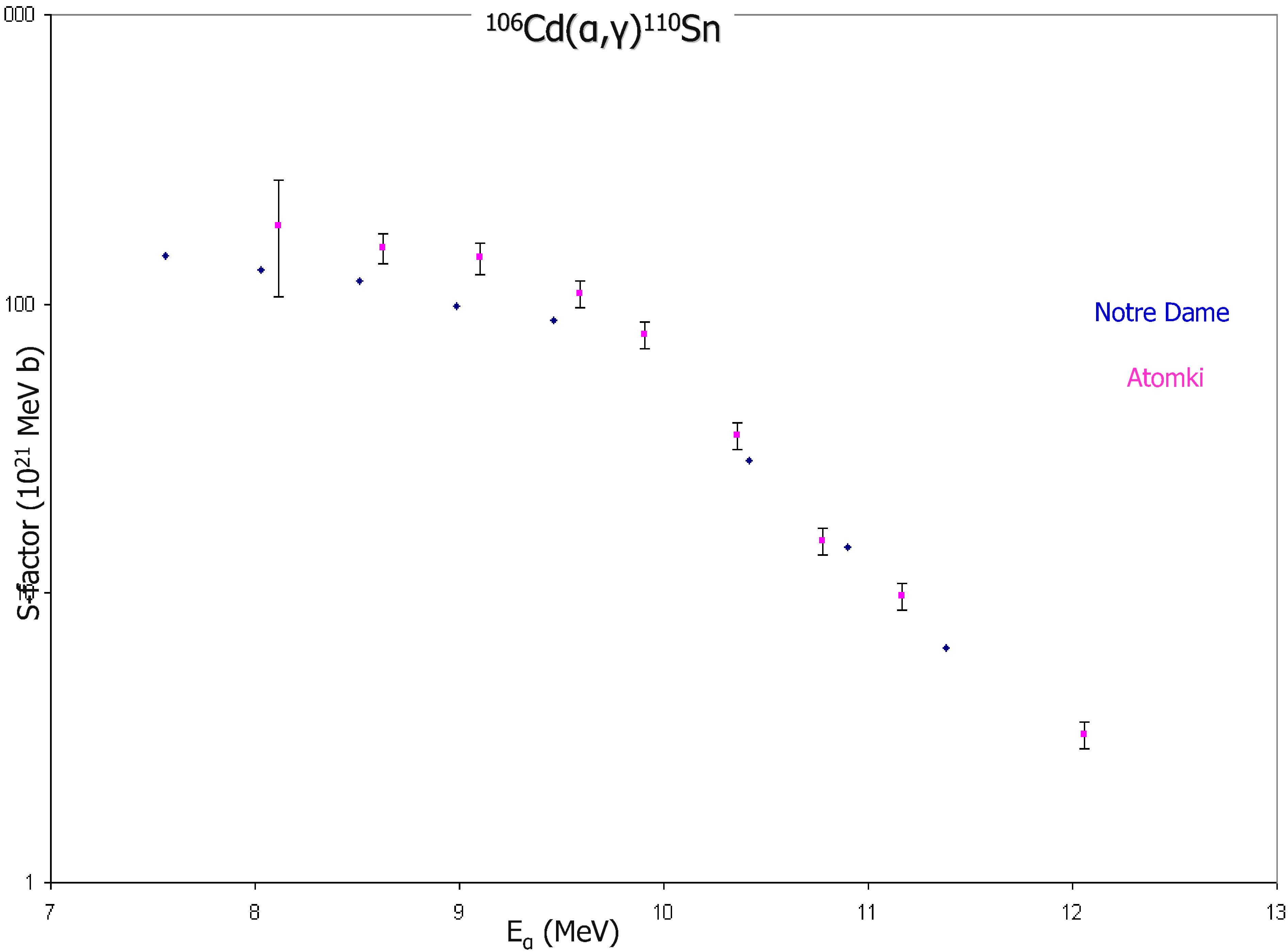
Our counting system consisted of two clover detectors in close geometry


Distance from target to crystal: 9 mm
10 cm lead bricks
3 mm Copper plates
CLOVER 2
CLOVER 1
ORTEC
Detector 2



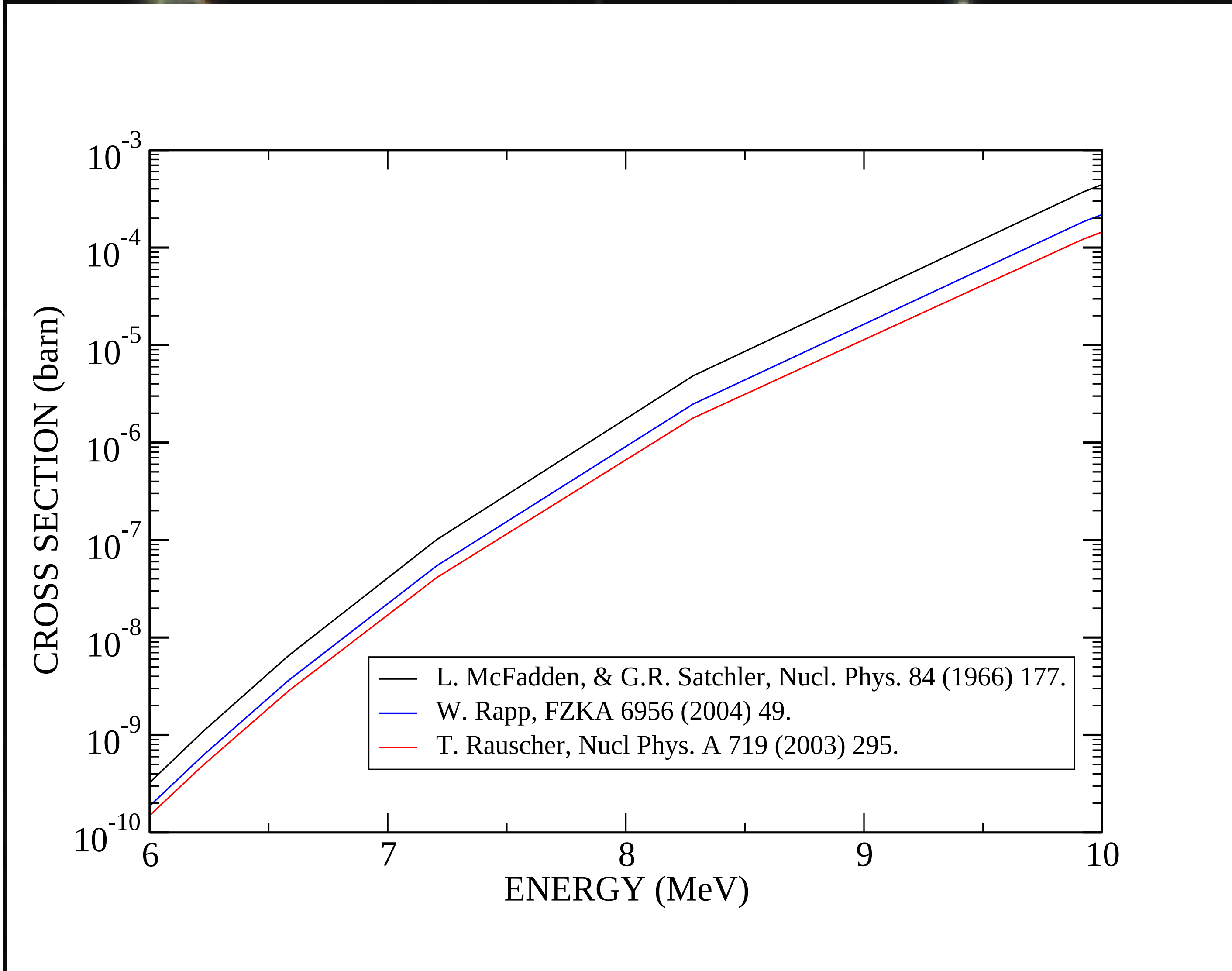
$^{112}Sn(\alpha,\gamma)^{116}Te$
Cross Section (barn)
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
7
8
9
10
11
12
13
$E_{C.M.}$ (MeV)
NON-SMOKER
629 keV
638 keV
932 keV
1294 keV


$^{106}Cd(\alpha,\gamma)^{110}Sn$
Notre Dame
Cross Section (μb)
E_α (MeV)
1000
100
10
1
0.1
0.01
7
8
9
10
11
12
13
14



$^{106}Cd(\alpha,\gamma)^{110}Sn$
000
100
1
S-factor (10^{21} MeV b)
7
8
9
10
11
12
13
E_α (MeV)
Notre Dame
Atomki

Experiment vs. Theory



V: data agrees with red
Blue: 1.5 larger σ
Black: 4.5 larger σ

eV: data agrees with blue
Red: 1.5 smaller σ
Black: 2 larger σ

Theoretical predictions for the ^{106}Cd(α,γ)-cross section
using different optical potentials

Conclusion

- Obtain final results of the current analysis
- More capture reactions on p-nuclei are needed (in particular (α,γ) at higher masses)
- Elastic scattering on the heavy p-nuclei (above A=120) …for reliable α-nucleus optical potential parameter.

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Master Target Maker: John Greene