CONTRIBUTION TO COMPILATION FROM MONGOLIA AND NUCLEAR PHYSICS ACTIVITY AT THE NUCLEAR RESEARCH CENTER, NATIONAL UNIVERSITY OF MONGOLIA

M.Odsuren, National University of Mongolia

TOPICS

- **CONTRIBUTION TO COMPILATION FROM MONGOLIA**
- **BRIEF INTRODUCTION OF THE NRC**

Status of Compilation @NRC

1. HISTORICAL BACKGROUND

COMPILATION /MONGOLIA/ -since 2014

- Heavy-ion (A>12) induced reaction data (West European countries)
- Mainly data measured at INFN/LNL, Legnaro, Italy
- Not intensively but step by step (a month/article)
- Good quality of the database (original numerical data)

Officially no data centre responsible for compilation of heavy-ion induced reaction data measured at West European countries.

PROGRESS OF COMPILATION

- Assign entry number with D area
- Send a paper
- Numerical data (since 2015)

Send an e-mail about modification/correction

– Modification
– Correction
– Insert num.data?

– Compile entry
– Questions ?

We have received numerical data for all cases (2014-2016) so far, and it helps us to avoid compilation of digitized data.

Status of Compilation @NRC

COMPILATION @NRC D0799

Edit:
d0799
edit

Convert:
d0799
conv

NRDF
w/o data
CHEN
EXFOR
w/o data
CHEX
Graph

Bib
Data 0A
Data 0B
Data 0X
Data 1
Data 2

```
ENTRY            D0799   20160419                                   D079900000001
SUBENT         D0799001   20160419                                   D079900100001
BIB                  11         41                                   D079900100002
TITLE       Pathway for the production of neutron-rich isotopes     D079900100003
            around the N=126 shell closure                          D079900100004
AUTHOR      (Y.X.Watanabe, Y.H.Kim, S.C.Jeong, Y.Hirayama, N.Imai,  D079900100005
             H.Ishiyama, H.S.Jung, H.Miyatake, S.Choi, J.S.Song,    D079900100006
             E.Clement, G.de France, A.Navin, M.Rejmund, C.Schmitt, D079900100007
             G.Pollarolo, L.Corradi, E.Fioretto, D.Montanari,       D079900100008
             M.Niikura, D.Suzuki, H.Nishibata, J.Takatsu)           D079900100009
INSTITUTE   (2JPNKEK)                                               D079900100010
            (3KORNSU) Department of Physics and Astronomy           D079900100011
            (3KORNSU) Institute for Nuclear and Particle            D079900100012
                      Astrophysics                                  D079900100013
            (3KORKOR) Institute for Basic Science                   D079900100014
            (2FR GAN)                                               D079900100015
            (2ITYTUR)                                               D079900100016
            (2ITYPAD)                                               D079900100017
            (2ITYUPV)                                               D079900100018
            (2FR PAR) Institut de Physique Nucleaire, IN2P3-CNRS    D079900100019
            (2JPNOSA)                                               D079900100020
REFERENCE   (J,PRL,115,172503,2015)                                 D079900100021
            Main reference. See also TITLE and AUTHOR.              D079900100022
            (J,EPJ/CS,66,03044,2014)                                D079900100023
            Preliminary cross sections (arb.units) in figs          D079900100024
            (J,NIM/B,317,752,2013)                                  D079900100025
            Preliminary cross sections (counts) in figs             D079900100026
PART-DET    (G,HF)                                                  D079900100027
INC-SOURCE  Beam intensity is 0.25 particle-nA.                     D079900100028
SAMPLE      - Chemical-form of target is element.                   D079900100029
            - Physical-form of target is solid.                     D079900100030
            - Target-thickness is 1.3 mg/cm2.                       D079900100031
            (78-PT-198,ENR=0.916)                                   D079900100032
FACILITY    (SYNCH,2FR GAN)                                         D079900100033
DETECTOR    (MAGSP) VAMOS++ spectrometer consists of a pair of      D079900100034
                    quadrupole magnets, a dipole magnet. The        D079900100035
                    scattering angle, kinetic energy, ionic         D079900100036
                    charge, mass and atomic number of the detected  D079900100037
                    particles were determined.                      D079900100038
            (IOCH) To detect fragments.                             D079900100039
            (GE) To detect gamma rays from fragments.               D079900100040
ADD-RES     (COMP) Optical model                                    D079900100041
HISTORY     (20160401R) Received by e-mail from X.Watanabe          D079900100042
            (20160415C) M.Odsuren and N.Otsuka                      D079900100043
ENDBIB               41          0                                  D079900100044
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COMPILATION @NRC D0799

Compilation @NRC

Reaction

Reaction guide

	Reaction I		Reaction II	
Target:	none	198Pt	none	198Pt
Projectile:	none	136Xe	none	136Xe
Emit.part.1:	X	none	Elastic	none
Residual:	Nucleus	none	none	none

Physical Quantity (EXFOR) guide Reaction Dict.

Reaction I: ,IPA

Reaction II: ,DA

The error bars shown are typically ~25% and include acceptance correction (~15%), extrapolation of the ionic charge distribution (~5%), particle identification (~0.3%), statistics (~3%), and normalization (~20%).

Error and Comment

Syst. Error (1-sigma)	T.	none	% (	none)
	1.	11[18	% (	acceptance correction (symmetric))
	2.	1[22	% (	extrapolation of the ionic charge distribution (unsymmetric: 1%-2)
	3.	0[3	% (	particle identification (unsymmetric: 0-3% for both upward and d( )
	4.	17[21	% (	normalization (unsymmetric: 17% for upward, 21% for downwar( )
Stat. Error (1-sigma)		0.1[10	% (	statistics (symmetric))

COMPILATION @NRC D0799

Status of Compilation @NRC

```
SUBENT        D0799003   20160419                                    D079900300001
BIB                 5         18                                    D079900300002
REACTION    (78-PT-198(54-XE-136,X)ELEM/MASS,,IPA)                   D079900300003
MONITOR     (78-PT-198(54-XE-136,EL)78-PT-198,,DA)                   D079900300004
EN-SEC      ANG is polar angle (lab.) between beam and prompt        D079900300005
            gamma                                                    D079900300006
ERR-ANALYS  (ERR-1,11.,18.) acceptance correction (symmetric)        D079900300007
                          (11-18%)                                   D079900300008
            (ERR-2,1.,22.) extrapolation of the ionic charge         D079900300009
                          distribution (unsymmetric: 1%-22% for      D079900300010
                          upward, 1%-8% for downward) (1-22%)        D079900300011
            (ERR-3,0.,3.) particle identification (unsymmetric:      D079900300012
                          0-3% for both upward and downward)         D079900300013
                          (0-3%)                                     D079900300014
            (ERR-4,17.,21.) normalization (unsymmetric: 17% for      D079900300015
                           upward, 21% for downward) (17-21%)        D079900300016
            (ERR-S,0.1,10.) statistics (symmetric) (0.1-10%)         D079900300017
STATUS      (TABLE) Plotted in Fig.1 (b-j), Fig.2 (a-b) and Fig.4     D079900300018
                   of Phys. Rev. Letts. 115, 172503, 2015            D079900300019
            (DEP,D0799002) Rutherford ratio data given               D079900300020
ENDBIB              18          0                                    D079900300021
COMMON               2          3                                    D079900300022
ANG-MIN     ANG-MAX                                                  D079900300023
ADEG        ADEG                                                     D079900300024
 24.         34.                                                     D079900300025
ENDCOMMON           3          0                                    D079900300026
DATA                5        175                                    D079900300027
ELEMENT     MASS        DATA        -ERR-T      +ERR-T               D079900300028
NO-DIM      NO-DIM      MB          MB          MB                   D079900300029
        50.        118.     4.9E+00     1.4E+00     1.3E+00          D079900300030
        50.        119.     5.9E+00     1.6E+00     1.5E+00          D079900300031
        50.        120.     6.4E+00     1.7E+00     1.6E+00          D079900300032
        50.        121.     6.0E+00     1.6E+00     1.4E+00          D079900300033
        50.        122.     4.8E+00     1.2E+00     1.1E+00          D079900300034
        50.        123.     3.7E+00     9.4E-01     8.5E-01          D079900300035
        50.        124.     2.5E+00     6.5E-01     5.8E-01          D079900300036
        50.        125.     1.6E+00     4.0E-01     3.6E-01          D079900300037
        50.        126.     9.1E-01     2.3E-01     2.2E-01          D079900300038
        50.        127.     4.8E-01     1.2E-01     1.2E-01          D079900300039
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2. NUCLEAR RESEARCH CENTRE

The NRC/NUM is an educational and research institution in Mongolia, which carries out basic and applied research in low energy nuclear physics.

THE MISSION of NRC is to be the leading national institute that conducts both education/training and research to obtain new information and results, to develop new methodology and technology in basic and applied nuclear physics, and also to develop equipment and devices.

HISTORICAL BACKGROUND

1956: First physicists sent to JINR, Dubna for nuclear study

1965: Nuclear research group (later Nuclear Research Lab) at the NUM organized (Neutron generator is installed from JINR)

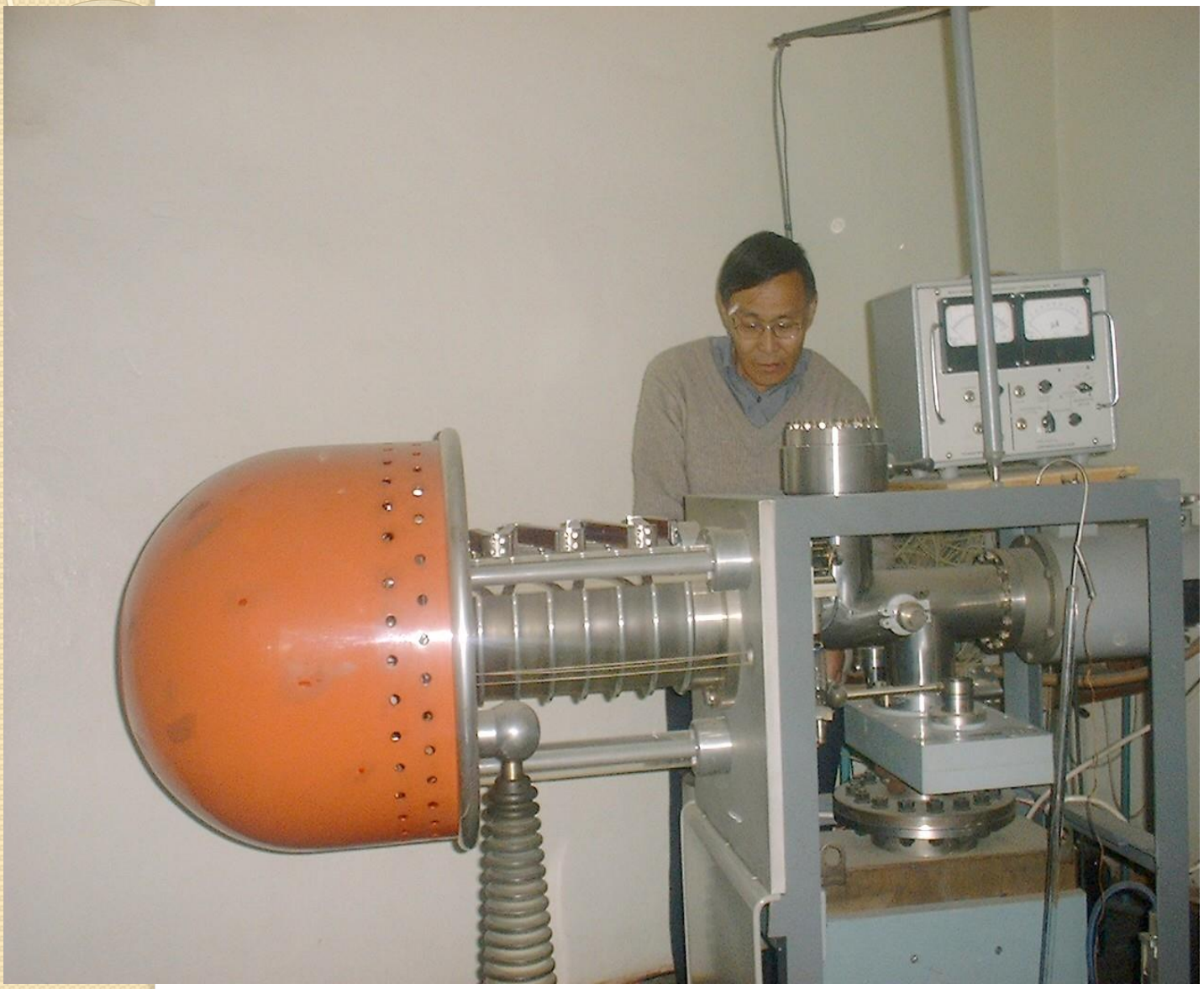
1991: Electron Cycle Accelerator (Microtron) 22 MeV installed at the Applied Nuclear Physics Section, Mongolian Academy of Science.

1997: NRL/NUM & ANPS/MAS were merged and reorganized as the Nuclear Research Center, NUM by the Government Resolution No 1997/31.

HUMAN RESOURCE (academic staff)

Positions	FT	PT
Director	1	
Accountant		40%
Scientific secretary		40%
Principal researcher	2	
Senior researcher	2	40%
Researcher	5	
Junior researcher	6	
Senior engineer	1	
Engineer	1	
Co-researcher		4x30% ≈1
Total	**20**	
Professor, Instructor & TA		3+1

NUCLEAR RESEARCH CENTER
NEUTRON GENERATOR



E=14MeV

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

NUCLEAR RESEARCH CENTER
^{252}Cf-NEUTRON SOURCE

$$F = 10^{9}\, s^{-1}$$

NUCLEAR RESEARCH CENTER
MICROTRON MT-22

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

$$I_e = 20 \mu A$$

$$Y_\gamma = 10^{12} s^{-1}$$

$$F_n = 10^8 cm^{-2} s^{-1}$$

NUCLEAR RESEARCH CENTER
MICROTRON MT-22

NUCLEAR RESEARCH CENTER
MICROTRON MT-22

NUCLEAR RESEARCH CENTER
CRYOGENIC INSTALLATION

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

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

NUCLEAR RESEARCH CENTER
X-RAY FLUORESCENT SPECTROMETER

$$\text{Re}\,solution = 180eV$$

$$at 5.9KeV$$

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

NUCLEAR RESEARCH CENTER
TOTAL REFLECTION X-RAY SPECTROMETER

NUCLEAR RESEARCH CENTER
DOSIMETER LABORATORY

TLD

DOSIMETER

NUCLEAR RESEARCH CENTER
NUCLEAR DATA LABORATORY

NUCLEAR RESEARCH CENTER
LIBRARY

NUCLEAR RESEARCH CENTER

- **RESEARCH FIELDS:**

1. BASIC NUCLEAR PHYSICS:

- Nuclear reactions
- Neutron physics
- Nuclear spectroscopy

2. NUCLEAR ANALYTICAL METHODS:

- Neutron activation analysis
- Photo activation analysis
- X-ray fluorescence analysis

3. NUCLEAR TECHNOLOGY

- Radiation technology
- Uranium technology
- Nuclear power technology

Theoretical and experimental study of fast neutron induced reaction, photo-reactions, structure of light nuclei

Geological, biological, agricultural, environmental (urban air pollution) samples.

Pre-feasibility studies on nuclear energy utilization, uranium exploration and enrichment, HRD …

Basic Nuclear Physics

1. **Experimental Study of Fast Neutron Induced (n,α) , (n,p) Reactions**
   (In collaboration with JINR, Dubna and Peking University, Beijing).

2. **Systematical Analysis of Fast Neutron Induced (n,α), (n,p) Reaction Cross Sections.**

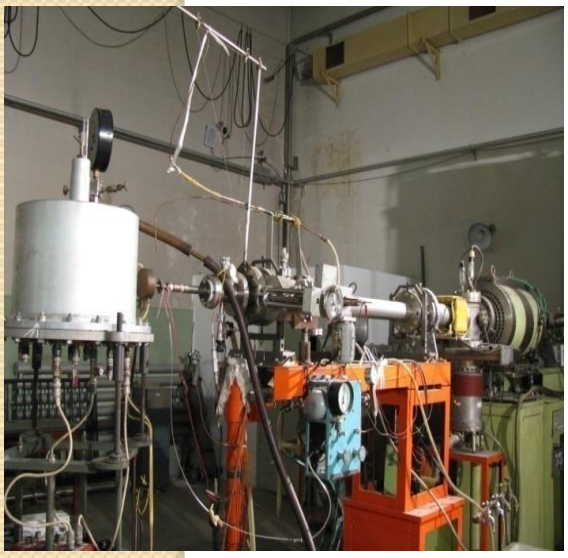
3. **Photo-activation Analysis.**

4. **Theoretical Study of Light Nuclei Cluster Structure**
   (In collaboration with Hokkaido University, Japan).

I. Experimental Study of Fast Neutron Induced (n,α) Reactions

Collaboration: Institute of Heavy Ion Physics, Peking University, Beijng.
Frank Laboratory of Neutron Physics, JINR, Dubna.
Nuclear Research Center, NUM, Ulaanbaatar

Neutron Scource - > Van de Graaff Accelerators
Neutron Monitor -> Long Counter and Fission Chamber
Alpha detector -> Ionization Chambers



Neutron beam hall at the Heavy Ion Physics Insititute. Peking University, Beijing.

High pressure small ionization chamber

Neutron beam hall at the Neutron Physics Laboratory, JINR, Dubna.

I. Experimental Study of Fast Neutron Induced (n,α) Reactions

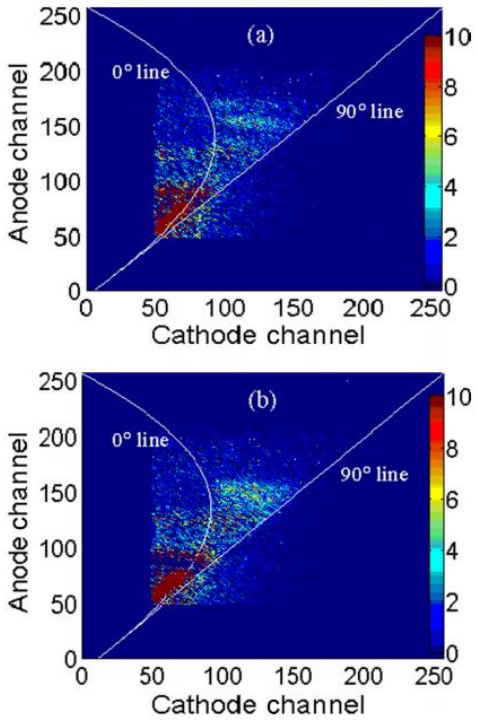
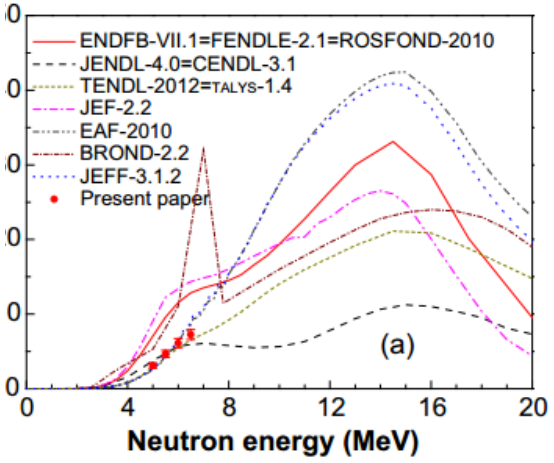
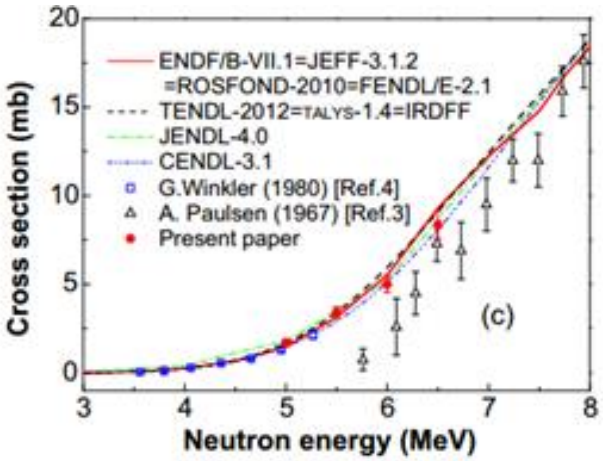


FIG. 2. (Color online) Two-dimensional foreground spectrum of the forward direction at $E_n = 6.5$ MeV, (a) for the $^{57}Fe(n,\alpha)^{54}Cr$ reaction and (b) for the $^{63}Cu(n,\alpha)^{60}Co$ reaction.



Measured cross section of the $^{57}Fe(n,a)^{54}Cr$ reaction



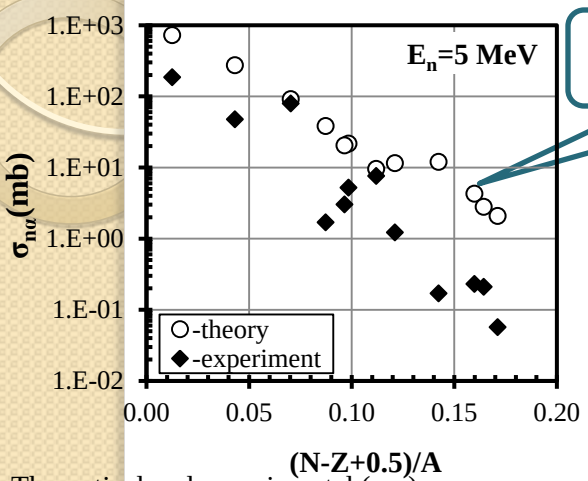
Measured cross section of the $^{63}Cu(n,a)^{60}Co$ reaction

Experimental Results

Measured Isotopes

№	E_n (MeV) / Nuclides		2.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
1	^{39}K	σ_{exp} (mb)			145±14		161±16		159±20	
2	^{40}Ca			156.4±8.9	173.2±9.5	179.8±9.9	197.8±10.9	207.3±11.6	216.9±15.0	
3	^{54}Fe			0.76±0.25	0.36±0.17		3.25±0.43		12.86±1.13	
4	^{56}Fe						1.05±0.23		5.1±0.7	
5	^{57}Fe					3.11±0.34	4.69±0.47	6.11±0.61	7.27±0.66	
6	^{58}Ni					47.4±5.0		75±16		95±20
7	^{63}Cu					1.69±0.17	3.40±0.32	5.01±0.47	8.35±0.80	
8	^{64}Zn		11.8±1.1	59.6±3.6		79.1±5.3	70.5±4.0	75.8±5.5	70.8±7	
9	^{66}Zn			1.75±0.20		5.38±0.59		10.05±0.98		
10	^{67}Zn			7.4±0.9		7.6±0.9		8.1±0.9		
11	^{95}Mo			0.7±0.07		1.22±0.12		1.70±0.17		

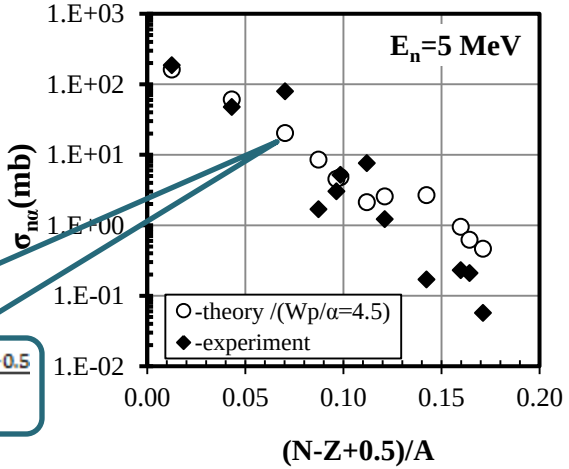
2. Systematical Analysis of (n,α) Reaction Cross Sections for E_n=4-6 MeV



$$\sigma(n,\alpha) = 2C\pi\left(R+\lambda\right)^2 e^{-K\frac{N-Z+0.5}{A}}$$

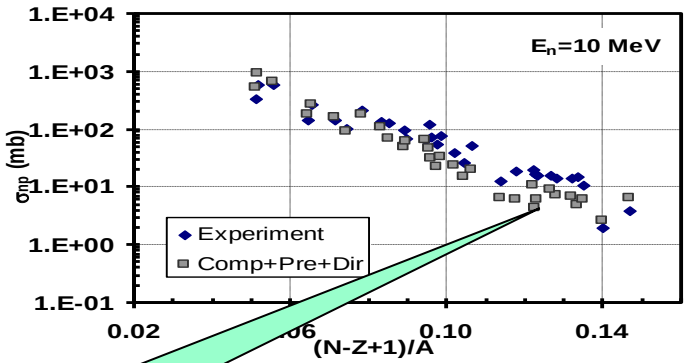
Theoretical and experimental (n,α) cross sections at E_n=5 MeV

$$\sigma(n,\alpha) = \frac{2C\pi\,(R+\lambda/2\pi)^2}{W_{n/\alpha}}\, e^{-K\frac{N-Z+0.5}{A}}$$



Experimental and theoretical (n,α) cross sections with α-cluster formation factor $W_{p/\alpha}$=4.5 for E_n=5 MeV.

(n,p) Reaction Cross Sections for E_n=4-20 MeV



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

3. Suggesting of New Method for Photo-activation Analysis

Bremsstrahlung gamma-rays were produced on the electron cyclic accelerator microtron MT-22 at the NRC, NUM

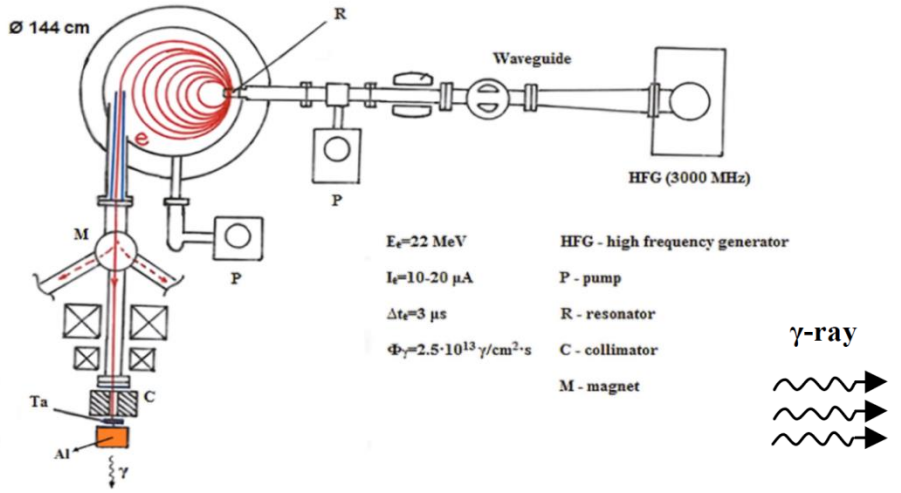
The electron cyclic accelerator microtron MT-22

E_e =22 MeV
I_e=3-5μA
ϕ_γ= 10^{12} γ/cm^{2}s

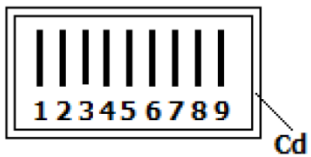
Irradiation time was 130 min
Measurement time was 10 min
Background measurement time 1000 s

Gamma-spectrometer

HP-Ge detector V=45cm^3
FWHM=2keV
at 1332.5 keV



γ-ray



Cu –monitor
Au-
Mo-
} samples

Theoretical formula

Correction factor is the ratio of the effective integral cross sections for the reference and analysing isotopes

The Schiff Formula is used

$$K = \frac{\sigma_{eff\,1}}{\sigma_{eff\,2}} = \frac{\int_{E_{th1}}^{E_{max}} \sigma_1(E_\gamma) f(E_\gamma) dE_\gamma}{\int_{E_{th2}}^{E_{max}} \sigma_2(E_\gamma) f(E_\gamma) dE_\gamma}$$

$$f(E_0, E_\gamma) = \frac{1}{16}\left[\left(1 + \frac{k^2}{E_0^2} - \frac{2k}{3E_0}\right)\left(\ln a + 1 - \frac{2}{b}\tan^{-1} b\right) + \frac{k}{E_0}\left(\frac{2}{b^2}\ln\left(1+b^2\right) + \frac{4\left(2-b^2\right)}{3b^3}\tan^{-1} b - \frac{8}{3b^2} + \frac{2}{9}\right)\right]$$

Where $b = \frac{2E_0 kZ^{\frac{1}{3}}}{111\ \mu_0 E_\gamma}$ **and** $\frac{1}{a} = \left(\frac{\mu_0 E_\gamma}{2E_0 k}\right)^2 + \left(\frac{Z^{1/3}}{111}\right)^2$

The sample mass (or element content)

$$m_2 = \left(\frac{S_2 A_2 \lambda_2}{S_1 A_1 \lambda_1}\right)\left(\frac{\theta_1 \varepsilon_1 I_1}{\theta_2 \varepsilon_2 I_2}\right)\frac{(1-e^{-\lambda_1 t_{i1}})e^{-\lambda_1 t_{d1}}(1-e^{-\lambda_1 t_{m1}})}{(1-e^{-\lambda_2 t_{i2}})e^{-\lambda_2 t_{d2}}(1-e^{-\lambda_2 t_{m2}})} m_1 K$$

The Lorentz-Shaped Resonance Cross Section is used

$$\sigma(E) = \frac{\sigma_{max}\Gamma^2 E_\gamma^2}{\left(E_{max}^2 - E_\gamma^2\right)^2 + \Gamma^2 E_\gamma^2}$$

If we use the same element for standard and sample:

$$m_2 = \left(\frac{S_2}{S_1}\right)\frac{e^{-\lambda_1 t_{d1}}}{e^{-\lambda_2 t_{d2}}} m_1$$

element content is determined without correction factor

3. Suggesting of New Method for Photo-activation Analysis

The correction factor is determined by three methods: experimental, theoretical

1 **Experimental correction factor**

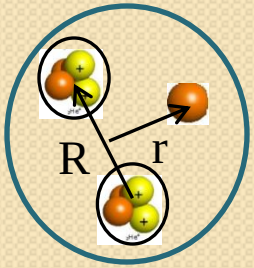
Sample	E_γ (keV)	K	Real mass (g)	Determined mass (g)	Relative uncertainty (%)
Au-4	332.9	7.1704	0.3409	0.3516	3.1
Cu-5	1345.8		0.0284	-	
Mo-6	739.4	1.9407	0.0817	0.0870	6.5
Cu-7	1345.8		0.0284	-	

2 **Theoretical correction factor**

Sample	E_γ (keV)	K	Real mass (g)	Determined mass (g)	Relative uncertainty (%)
Au-4	332.9	8.1801	0.3409	0.3082	9.6
Cu-5	1345.8		0.0284	-	
Mo-6	739.4	2.1620	0.0817	0.0781	4.4
Cu-7	1345.8		0.0284	-	

4. Theoretical Study of Light Nuclei Cluster Structur

Collaboration: Nuclear Reaction data Center, Hokkaido University, Sapporo
Research Center for Nuclear Physics (RCNP), Osaka University
Nishina Center for Accelerator-based Science, RIKEN
Nuclear Research Center, NUM, Ulaanbaatar, Mongolia



^{9}Be

α+α+n three body model is used.

Forbidden states

Hamiltonian $\hat{H} = \sum_{i=1}^{3} \hat{T}_i - \hat{T}_{c.m.} + \sum_{i=1}^{2} V_{\alpha n}(r_i) + V_{\alpha\alpha} + V_{PF}.$

α+n -> potential

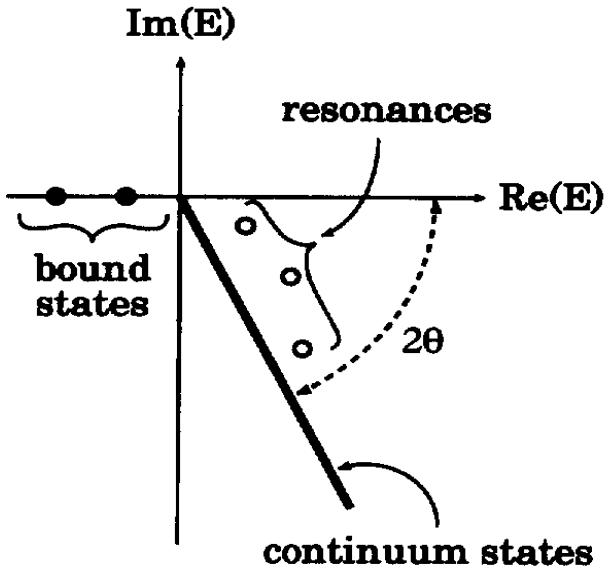
α+α -> potential

The Complex scaling method is applied.

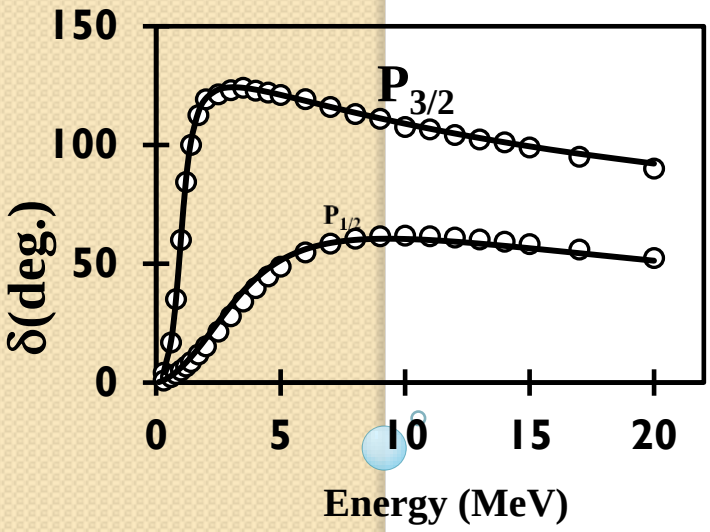
coordinate: $r \rightarrow re^{i\theta}$

momentum: $k \rightarrow ke^{-i\theta}$

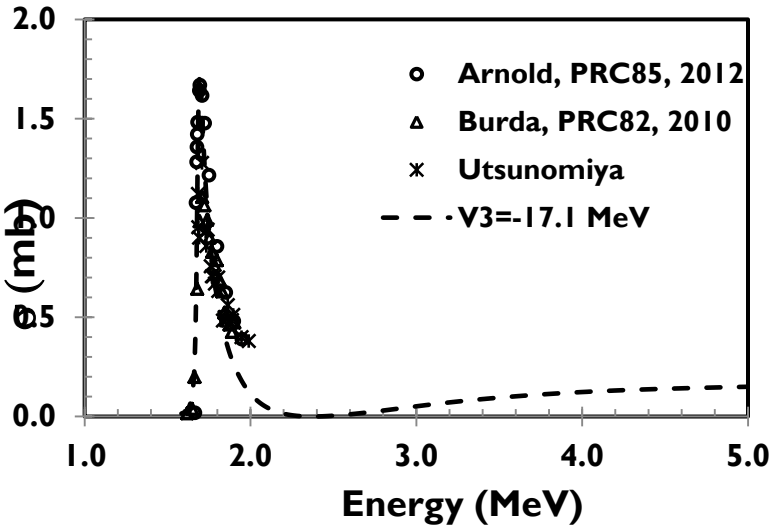
$$\hat{H}(\theta) = U(\theta)\hat{H}U^{-1}(\theta)$$



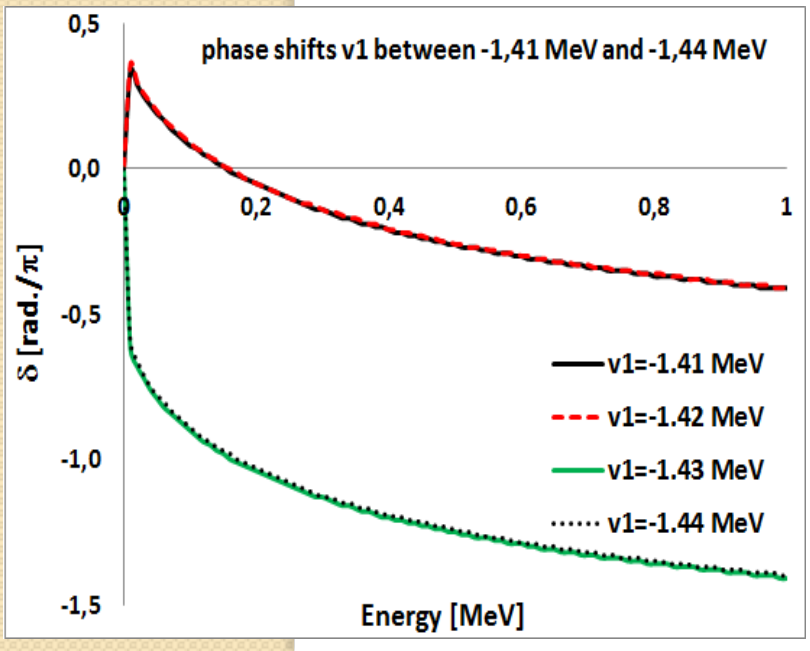
The phase shift for the ^{5}He system

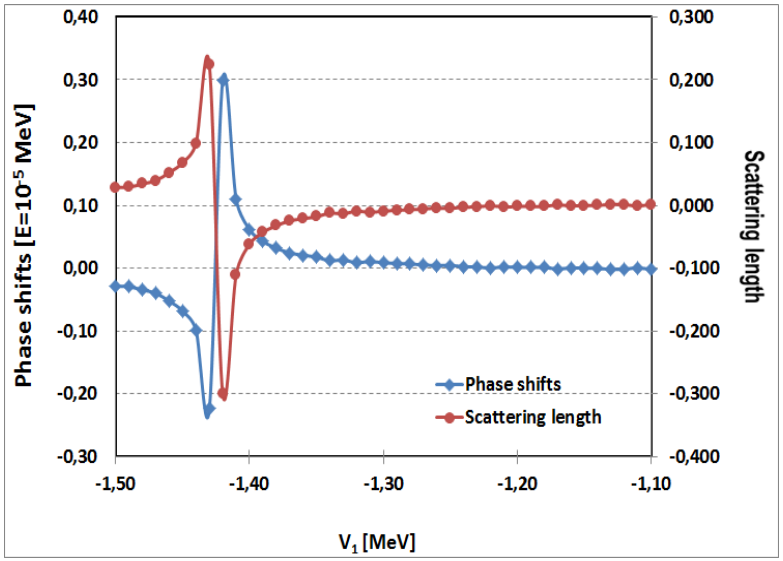


Reaction Cross Section for the ^{9}Be(1/2$^+$)



Virtual state





Thank you for your attention !