

最近の北大核反応データセンター 活動

K. Kato

Nuclear Reaction Data Center

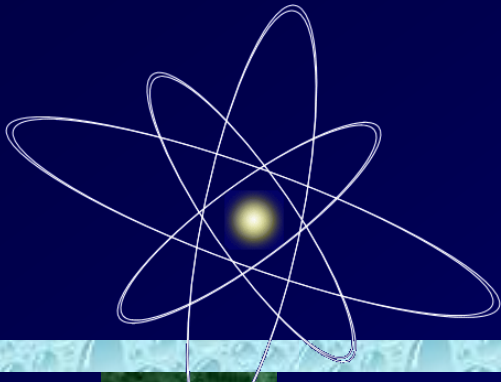
Hokkaido University

Sapporo

<http://www.jcprg.org/>

25 March, 2009,

RIKEN



Contents

1. Introduction

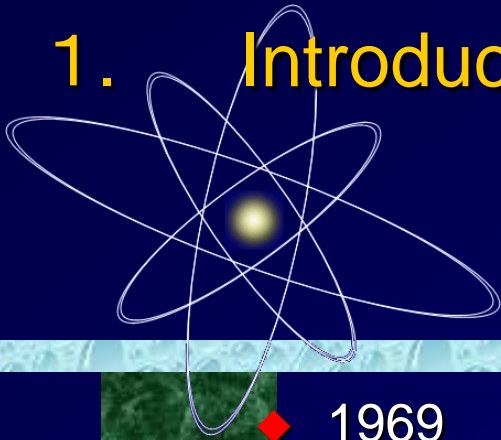
- 1-1. Brief History of NRDF
- 1-2. Homepage of JCPRG
- 1-3. What are nuclear data?

2. Subjects of Nuclear Reaction Data Center in Hokkaido University

- 2-1. Nuclear Reaction Data Compilation, and Development of Database Utility Systems
- 2-2. Evaluation of Nuclear Reaction Data
- 2-3. Asian Nuclear Reaction Data Collaboration

3. Summary

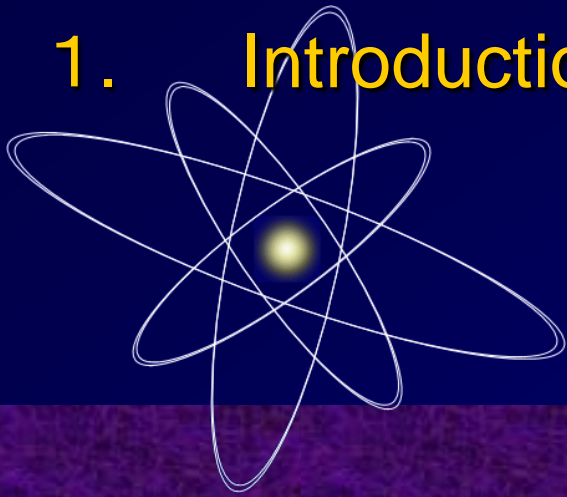
1. Introduction



History

- ◆ 1969
Format for exchange (EXFOR) agreed among 4 core (neutron) centres
- ◆ 1974
 - Consultant meeting for extension of 4 centres to neutron, charged-particle nuclear data (CPND) and photo nuclear data (PhND) centres (Karlsruhe, Kurchatov)
 - Data compilation project of JCPRG approved by Theoretical Nuclear Physics Society and the Experimental Nuclear Physics Society in Japan
- ◆ 1975
Consultant meeting for CPND compilation (Karlsruhe, Kurchatov, JCPRG)
- ◆ 1977
The first meeting of neutron data centres + CPND centres + PhND centre (CAJaD, Karlsruhe, JCPRG) : Kiev meeting
 - JCPRG: Differential data (Academic oriented)
 - Karlsruhe, Kurchatov: Cross section
- ◆ 1983
RIKEN joined to the network (~2000)

1. Introduction

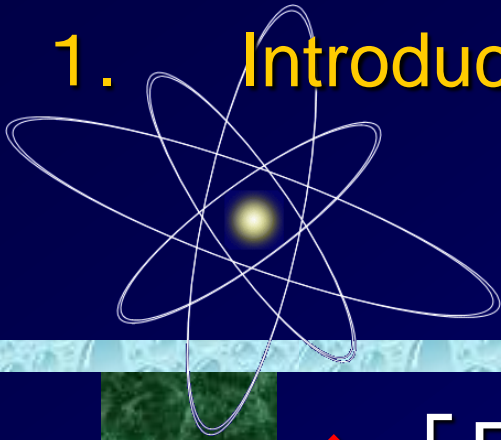


Homepage of JCPRG

<http://www.jcprg.org/index-j.html>

- 1) 歴史の続き
- 2) データベース
- 3) その他

1. Introduction



核データ研究の目指すもの

- ◆ 「日本原子力学会誌」2001. 43巻
5月号から連載（4回）

「核データ」① 核データとは何か？

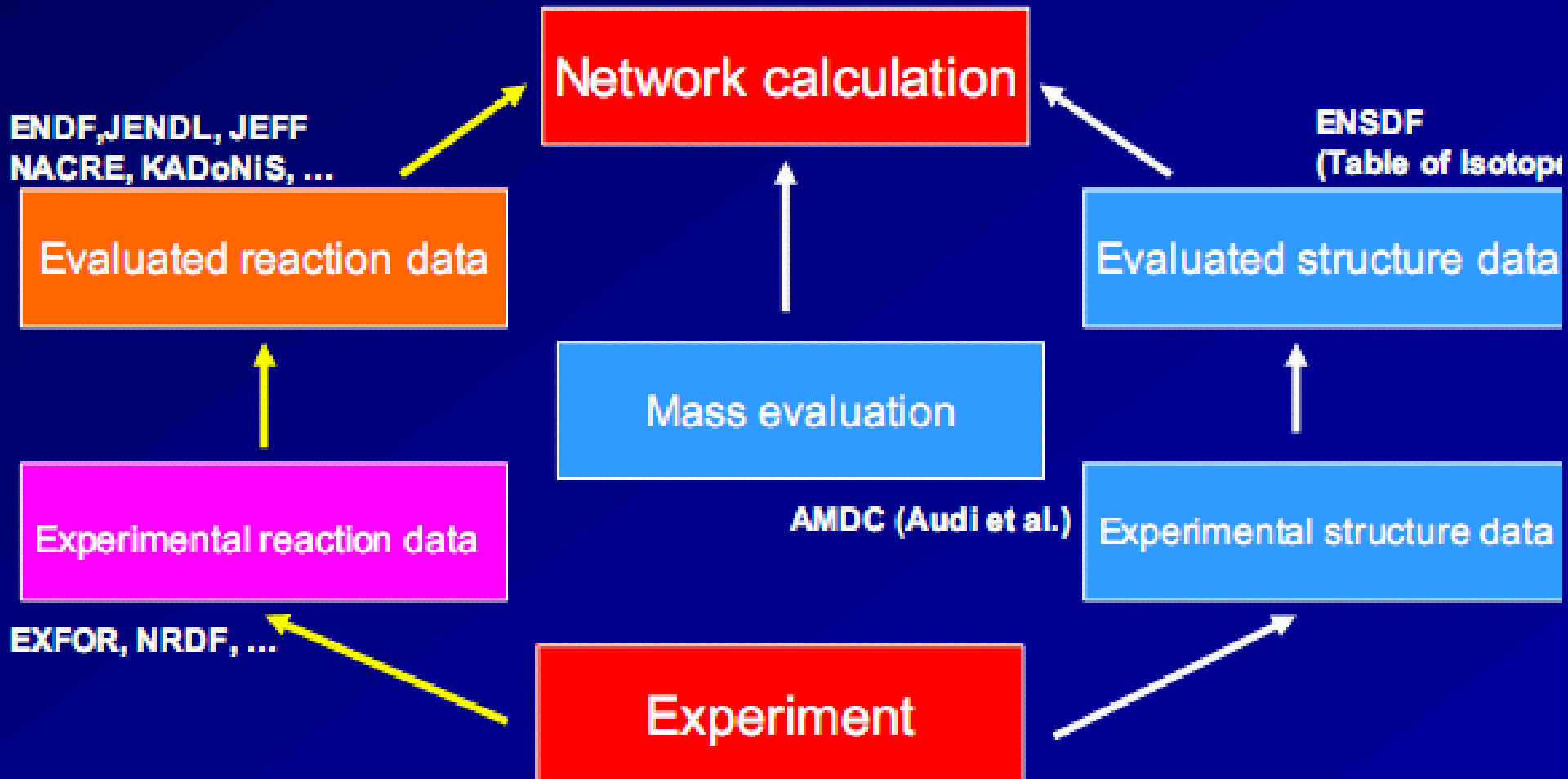
吉田 正、大澤孝明、瑞慶覧 篤、
深堀智生、馬場譲

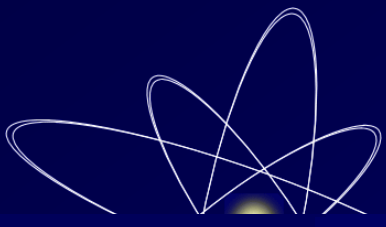
原子核についての人類の知識体系、原子核情報科学、
他に類するものがない。

実験に費用がかかる、容易でない。→ 核データの重要性

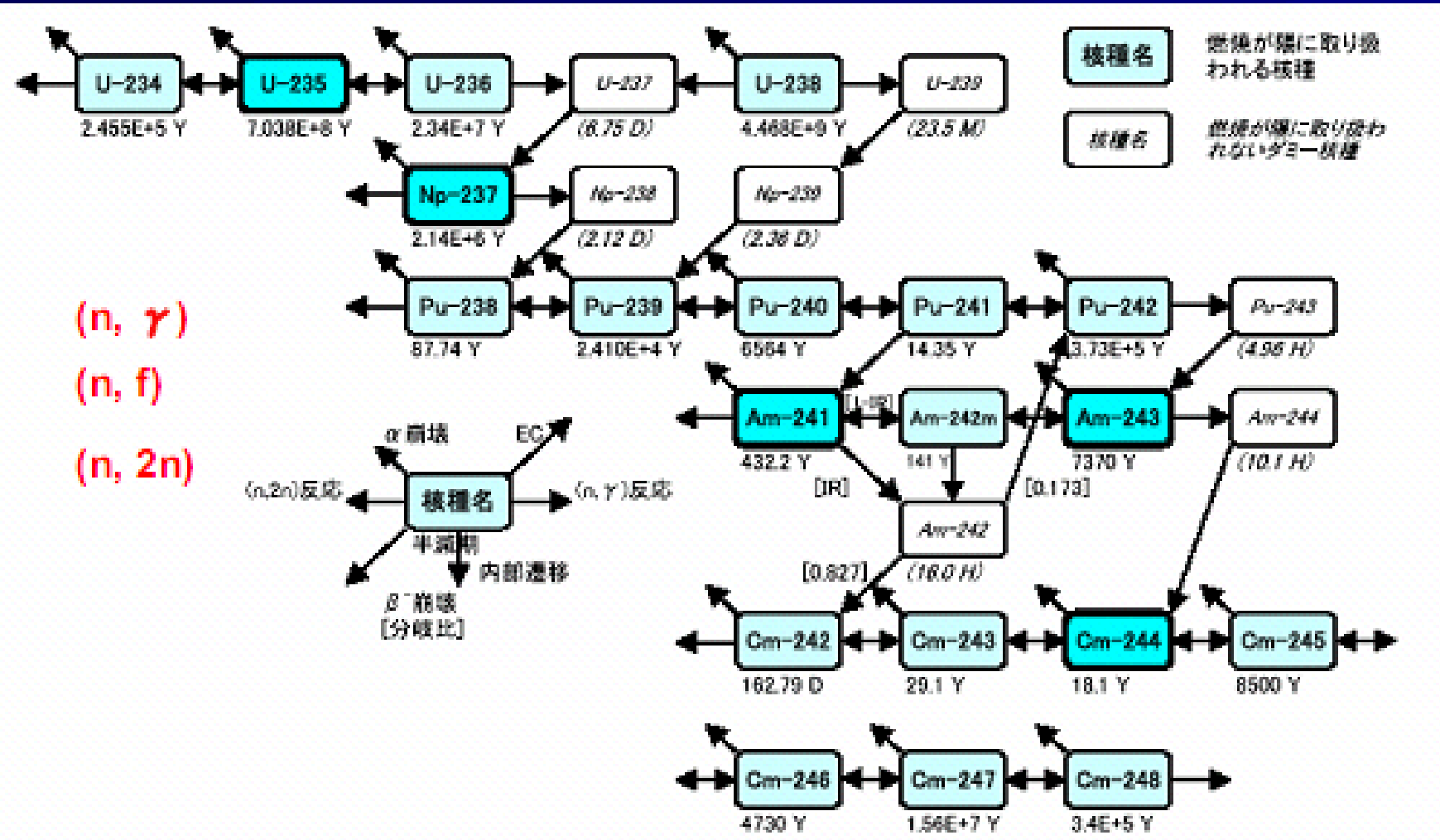
Nuclear Data → Network Calculations

$$\frac{dN_i(t)}{dt} = -(\lambda_i + \sigma_i \phi) N_i(t) + \sum_j f_{j \rightarrow i} \lambda_j N_j(t) + \sum_k g_{k \rightarrow i} \sigma_k \phi N_k(t)$$



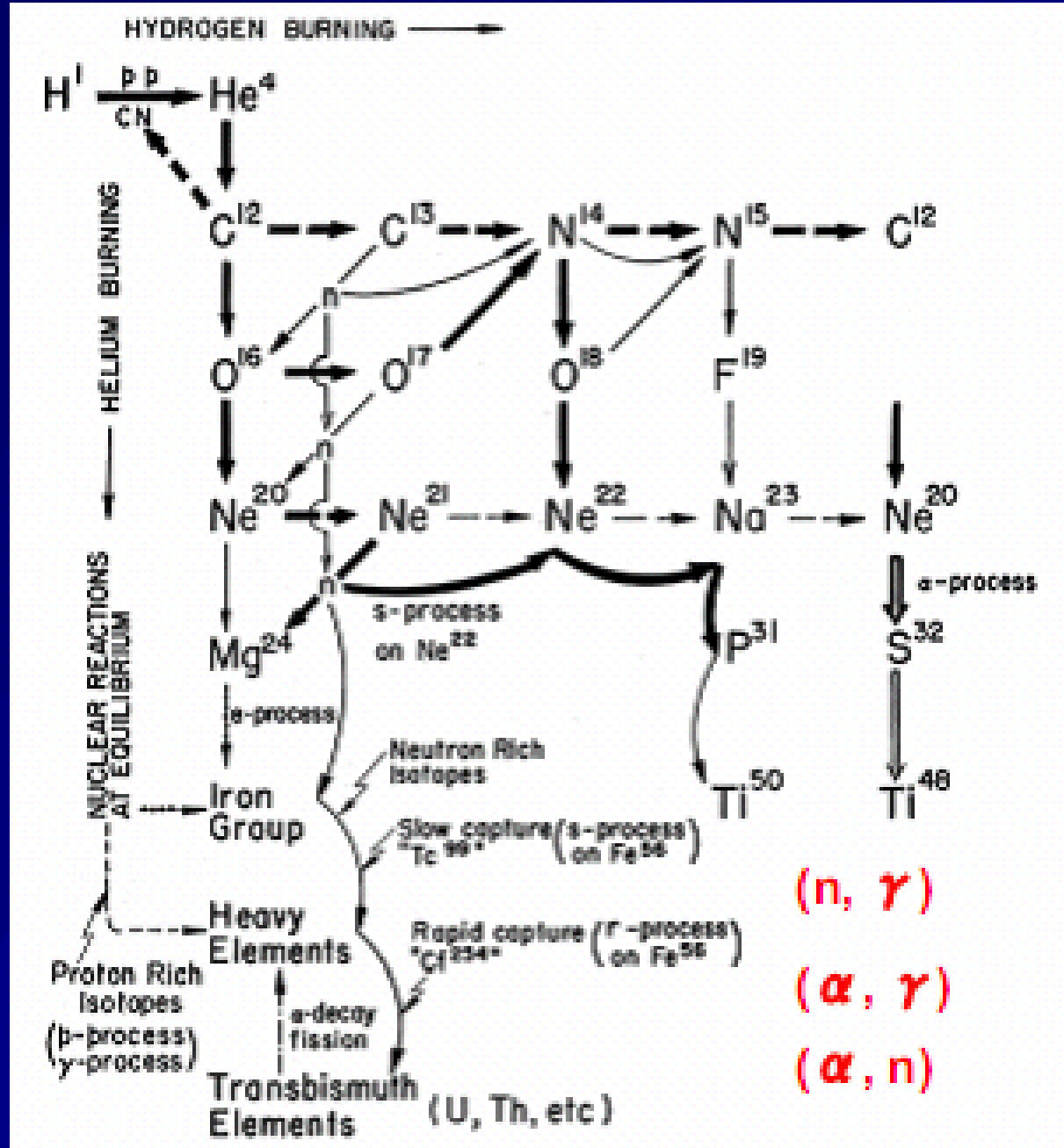


Network in Reactor Physics





Burning Chain of Astronuclearphysics



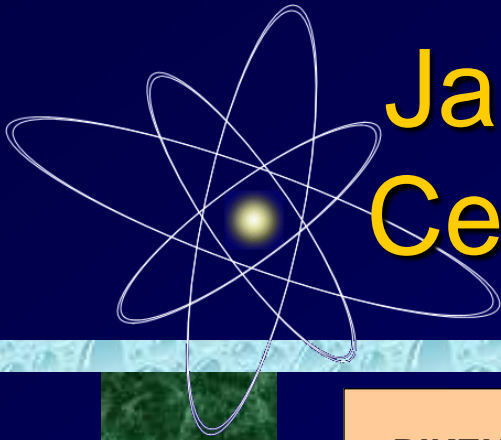
Schematic diagram of nuclear process in stars – E. M. Burbidge et al.,

(B² FH) Rev. Mod. Phys. 29 (1957)



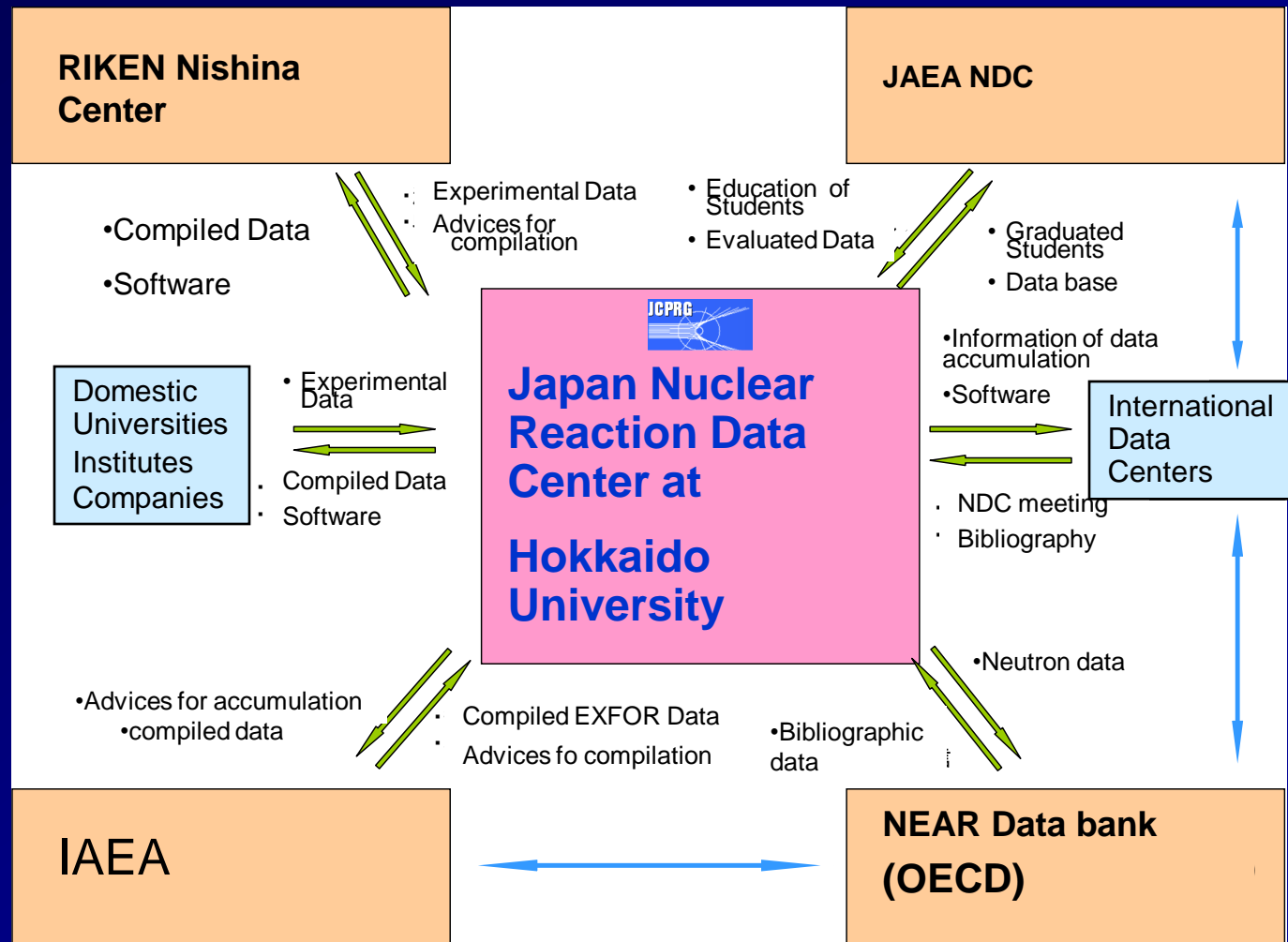
2. Subjects of Nuclear Reaction Data Center in Hokkaido University

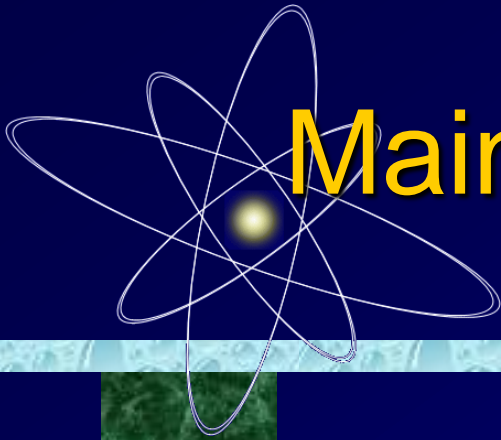
<http://www.jcprg.org/index-j.html>



Japan Nuclear Reaction Data Center at Hokkaido University

From April 1, 2007





Main Purposes of the Center

- 1. Nuclear Reaction Data Compilation, and Development of Database Utility Systems**
- 2. Evaluation of Nuclear Reaction Data**
- 3. Asian Nuclear Reaction Data Collaboration**



Members of JCPRG

◆ Advisory committee of JCPRG :

Abe, Yasuhisa(RCNP), Akaishi, Yoshinori (RIKEN/Nihon Univ.), Aoki, Yasuo(Tsukuba), Baba, Mamoru(Tohoku), Chiba, Junsei(Tokyo Science Univ.), Hasegawa, Akira (NEA-DB), Hatanaka, Yoshiharu(RCNP)), Ishihara, Masayasu (RIKEN), Kato, Kiyoshi(hokkaido), Katakura, Jun-ichi (JAEA), Kawai, Kouji(Kyushu), Kubono, Shigeru((Tokyo, CNS), Morinobu, Shunpei(RCNP), Noro, Tetsuo(Kyushu), Motobavashi, Toru(RIKEN), Nagae Tomofumi(KEK), Okamoto, Koichi (Atomic Ind.), Ohmuma, Hajime(Chiba Tech.), Tanaka, Hikonojo(Tohoku), Saito, Teijiro(Tohoku), Sakurai, Hiroyoshi (RIKEN), Tanaka, Hajime(Hokkaido), Utsunomiya, Hiroaki(Konan Univ.)

◆ Executive and Steering committee of JCPRG :

Kato, Kiyoshi (Hokkaido), Aoyama, Shigeyoshi (Niigata), Chiba, Masaki (Sapporo Gakuin), Hirabayashi, Yoshiharu(Hokkaido), Katayama, Toshiyuki (Hokusai Gakuen), Masui, Hiroshi (Kitami Tech.), Noto, Hiroshi (Hokusei Gakuen.), Ohnishi, Akira(hokkaido), Okabe, Shigeto (Hokkaido), Sakurai, Hiroyoshi(RIKEN)

◆ Compilations, System development and Secretaries :

Ashizawa, Takako (Hokkaido), Ito, Shin-ya (Hokkaido), Kurokawa, Chie(Hokkaido), Matsumiya, Hiroshi(Hokkaido), Murakami, Takaomi (Hokkaido), Suzuki, Ryusuke(Hokkaido), Togashi, Tomoaki (Hokkaido), Tsubakihara, Kousuke (Hokkaido), Yoshida, Hitomi



2.1.1

International Network of Nuclear Data Centres

<http://www.jcprg.org/index-j.html>



International Cooperation

Networks coordinated by IAEA:



◆ Nuclear Reaction Data Centres Network

Compilation (**EXFOR** and **CINDA**) and evaluation for nuclear reaction data (13 centres)

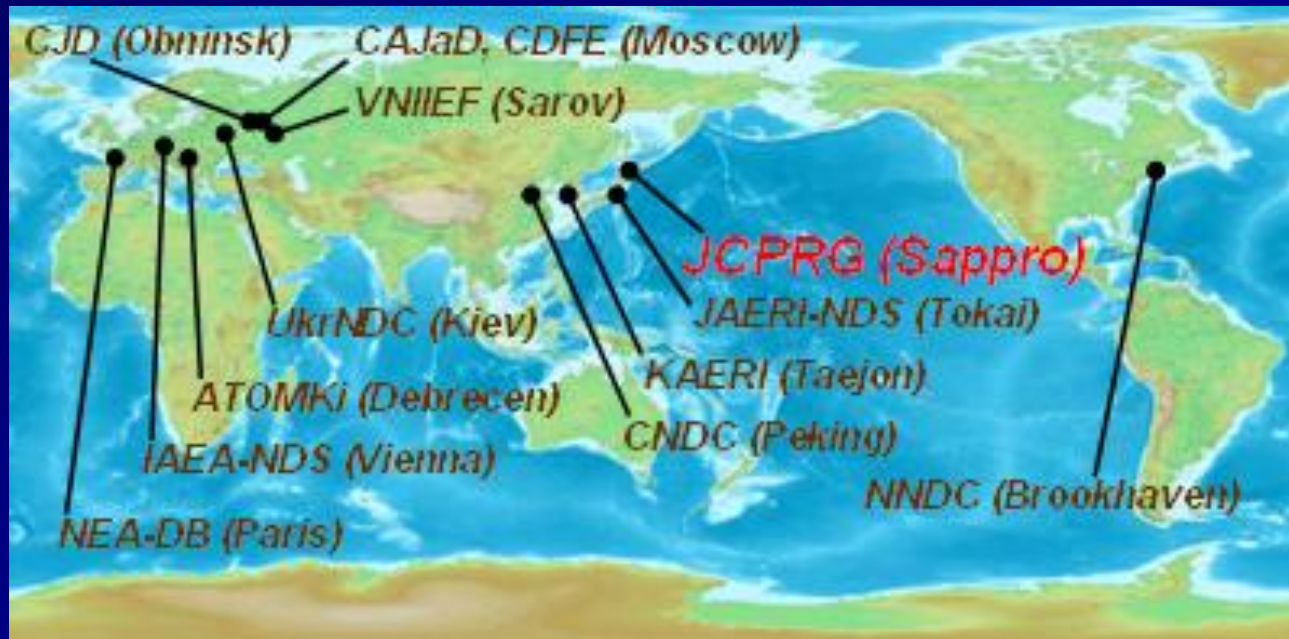
◆ Nuclear Structure Data Centres Network

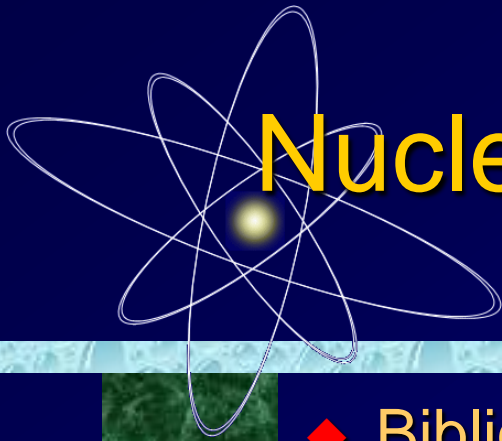
Evaluation for nuclear structure data **ENSDF** (16 centres)

Nuclear Data Centre Networks

◆ Nuclear Reaction Data Centres (13)

NNDC (Brookhaven), NEA-DB (Paris), NDS (IAEA),
CJD (Obninsk), ATOMKI (Debrecen), CIAE (Beijing),
JAEA-NDC (Tokai), JCPRG (Sapporo), KAERI –NDEL (Taejon),
CAJaD (Moscow), CDFE (Moscow), NPDC (Sarov),
UkrNDC (Kiev)





Nuclear Reaction Data Products

◆ Bibliography

CINDA

NSR

◆ Experimental Data

EXFOR

NRDF

◆ Evaluated Data

ENDF

JENDL

JEFF

Nuclear Data Services
International Atomic Energy Agency
1999-2103

EXFOR+CINDA

Database and Retrieval System

Version 1.10, March 2003

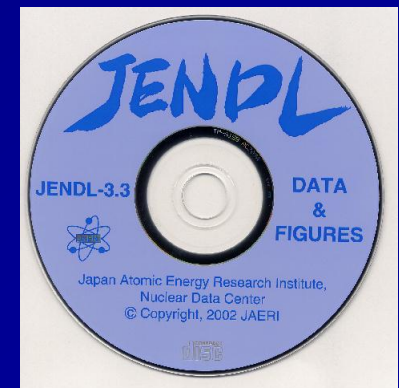
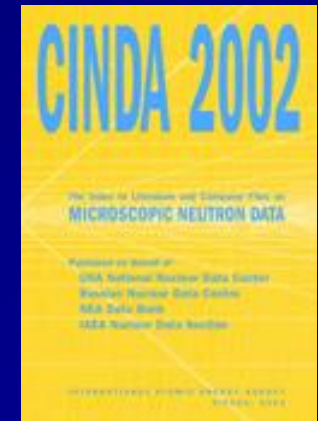
- + Advanced search
- + Plugged-in Dictionaries
- + Interactive graphics for cross sections
- + Does not need installation

EXFOR is a comprehensive library of experimental nuclear reaction data induced by neutrons, charged particles and photons.
Contents: 13,300 entries, 30,000 data tables.

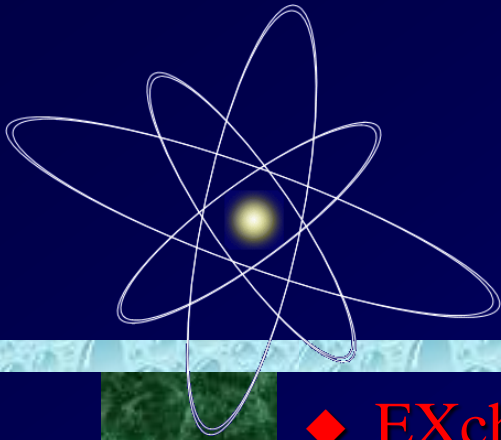
CINDA library contains bibliographical references to experimental nuclear reaction data and to calculations, reviews, compilations and evaluations of neutron reaction and spontaneous fission data.
Contents: 266,000 lines, 51,000 publications, 133,000 blocks.

Retrieval System has been written on Java2.

© These databases are a product of the Network of Nuclear Reaction Data Centers.



(Exchanged files are disseminated by each centres responsibility)



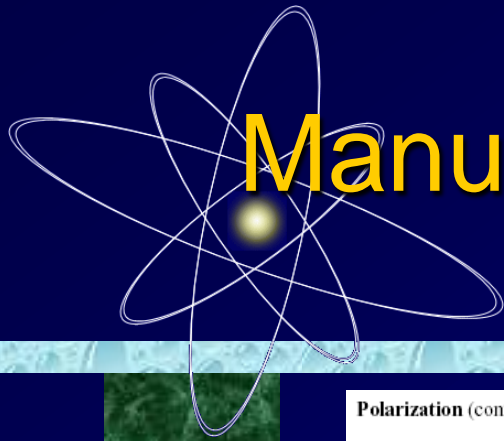
EXFOR

- ◆ **EXchange FORmat** agreed at 1969 among 4 core centres (NNDC, NEA-DB, IAEA-NDS, CJD)
- ◆ Coverage is complete for neutron data (in particular up to 20 MeV)
- ◆ Coverage less complete (but improving) for higher energy neutron, charged-particle induced and photonuclear data



Physical Quantity in Basic Criteria

- ◆ Cross section
- ◆ Diff. data with respect to angle ($d\sigma/d\Omega$)
- ◆ Diff. data with respect to energy ($d\sigma/dE$)
- ◆ Diff. data with respect to angle and energy ($d\sigma/d\Omega /dE$)
- ◆ Polarization data
- ◆ Product yields
- ◆ Fission product yields
- ◆ Thick target yields
- ◆ Differential thick target yields
- ◆ Resonance integrals
- ◆ Resonance parameters
- ◆ Reaction rates
- ◆ Gamma spectra
- ◆ ...



Manual for Compilers (LEXFOR)

Polarization (continued)

Analyzing Power: the relative difference in the cross sections for corresponding spin up vs. spin down.

Vector analyzing power (A_1 or $A_{i,0,0,0}$ and A_1 or $A_{0,1,0,0}$):

REACTION Coding: Modifier ANA in SF8.

Examples:

, POL/DA, , ANA Analyzing power, A_0 , incident projectile spin normal to scattering plane.

LON, POL/DA, , ANA Analyzing power, A_1 , incident projectile spin parallel to incident particle momentum in scattering plane (longitudinal).

Tensor analyzing power (A_{ij} or $A_{ij,0,0,0}$): initial spin state correlation parameters.

$$A_{yy} = A_{NN} = \epsilon f |P_0||P_1|$$

REACTION Coding: Modifier ANA in SF8, and a branch code in SF5 giving components of beam and target spin

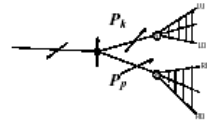
Example:

NN, POL/DA, , ANA Tensor analyzing power, A_{NN} , incident projectile and target spins normal to scattering plane.

Spin-Correlation Parameter (C_{kp} or $C_{0,0,k,p}$): final spin state correlation parameters.

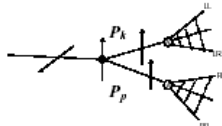
For spins in the scattering plane:

$$C_{kp} = \frac{d\sigma/d\Omega_{\uparrow\uparrow} + d\sigma/d\Omega_{\downarrow\downarrow} - d\sigma/d\Omega_{\uparrow\downarrow} - d\sigma/d\Omega_{\downarrow\uparrow}}{d\sigma/d\Omega_{\uparrow\uparrow} + d\sigma/d\Omega_{\downarrow\downarrow} + d\sigma/d\Omega_{\uparrow\downarrow} + d\sigma/d\Omega_{\downarrow\uparrow}} = \frac{1}{P_p P_t} \frac{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} - Y_{\uparrow\downarrow} - Y_{\downarrow\uparrow}}{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} + Y_{\uparrow\downarrow} + Y_{\downarrow\uparrow}}$$



For spins normal to the scattering plane:

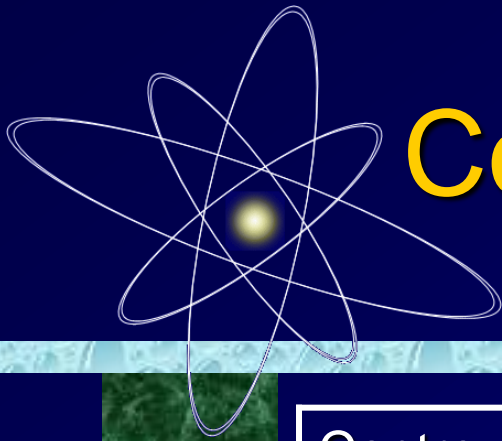
$$C_{NN} = \frac{1}{P_p P_t} \frac{(LL)(RL) + (LR)(RR) - (LL)(RR) - (LR)(RL)}{(LL)(RL) + (LR)(RR) + (LL)(RR) + (LR)(RL)}$$



LEXFOR "Polarization"

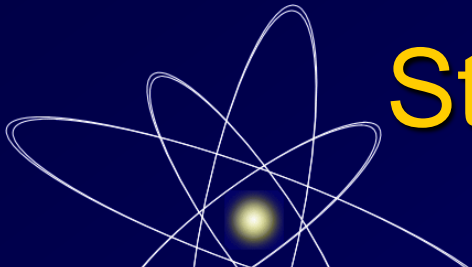


NRDC Meeting 2004
(@ NNDC)



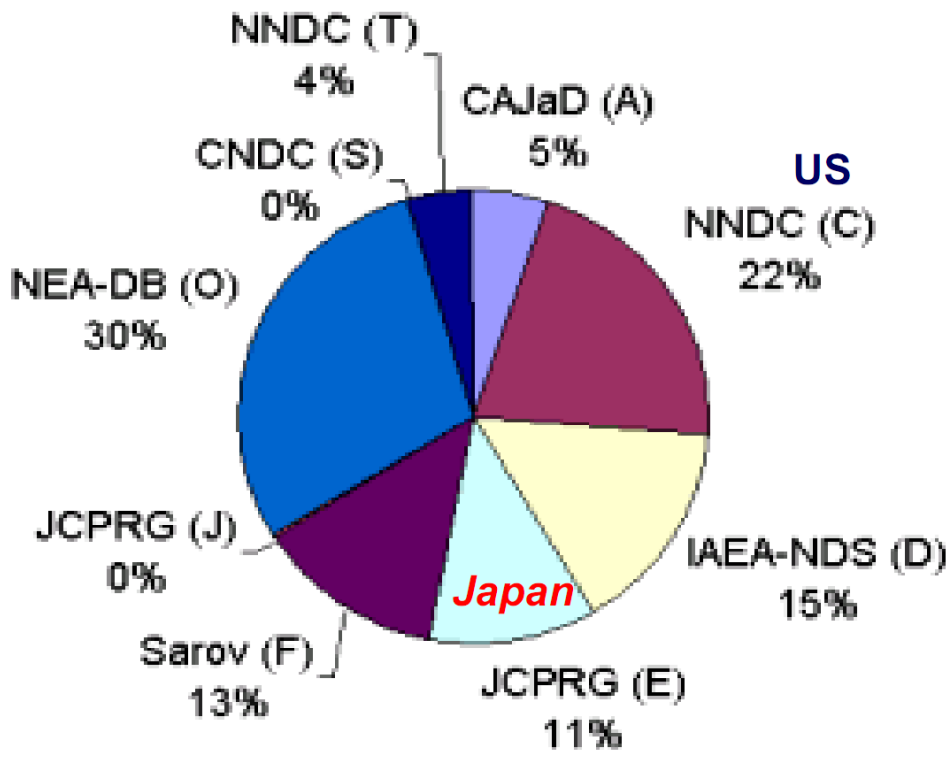
Compilation Responsibility

Centre	Responsibility
NNDC (NY)	Neutron+CPND+PhND from US+Canada
NEA-DB (Paris)	Neutron data from OECD-NEA countries
IAEA-NDS (Wien)	Neutron+CPND from “rest of the world”
CJD (Obninsk)	Neutron data from Russia
CAJaD (Moscow)	CPND from Russia
CDFE (Moscow)	PhND from “rest of the world”
CNDC (Beijing)	Neutron+CPND from China
JCPRG (Sapporo)	CPND+PhND from Japan
ATOMKI (Debrecen)	CPND from Debrecen and Brussels
UkrNDC (Kiev)	Neutron+CPND+PhND from Ukraine
NPDC (Sarov)	CPND (coordinated with other centres)



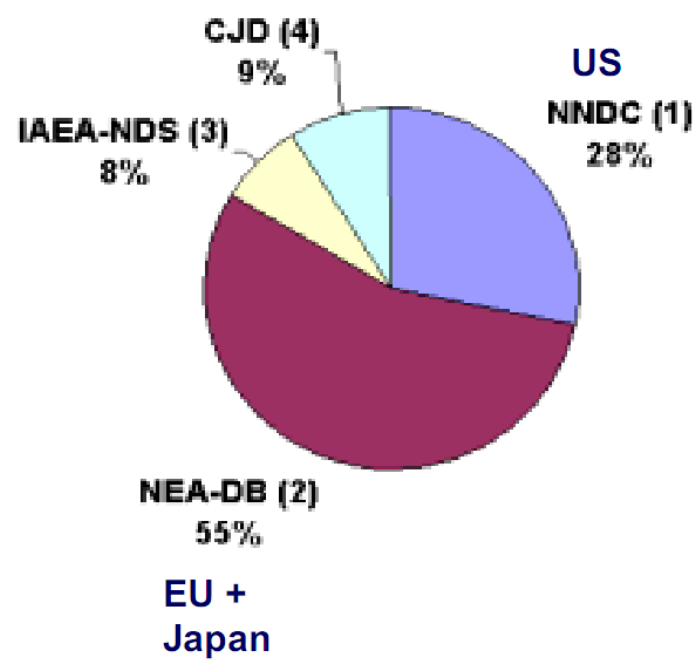
Statistics of Compiled Data in EXFOR (2003-2006)

Compilation Statistics (CPND)

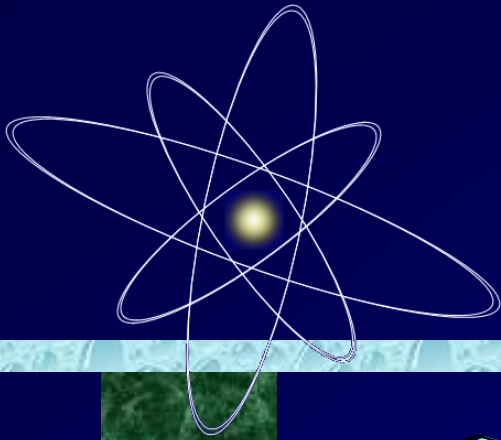


Neutron Induced Reaction Data (Data Center ID=1, 2, 3, 4)

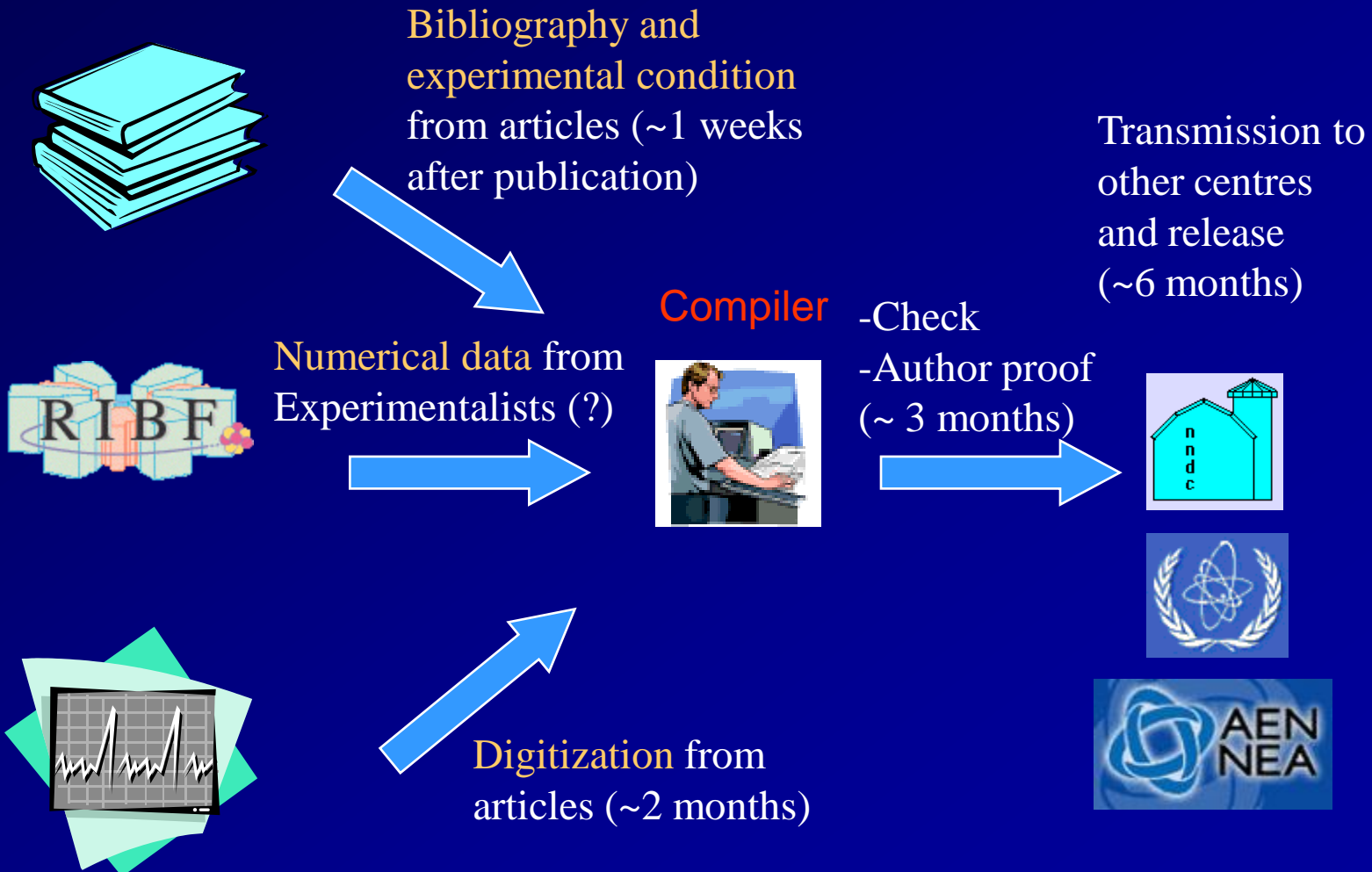
Compilation Statistics (Neutron)



Charged Reaction Data (JCPRG Contr. ~10%)
 E: CPRD produced in Japan
 J: Meson and anti-p data, K: Photo-Reaction Data
 R: Compiled by RIKEN DG



Compilation Process



Data Input System - HENDEL

Henkel and Eckert Editor E1670 - Netscape

E1670
Volume 407, 110 Physics Letters, Section B August 20 1997

Isoballic analog state of 11Li

T. Terasaki¹, S. Shinoura², Y. Arai², M. Hori², N. Imai², T. Kikuchi², S. T. Nakamura³, T. Amano⁴, H. Sakusa¹, T. Uchida⁵, Y. Watanabe¹
¹Institute of Physical and Chemical Analysis (IPAC)
²Department of Physics, Akiyoshi (St Paul) Univ., Y.
³Department of Physics, Univ. of Tokyo
⁴Deutscher Fachschriftenverlag

Add or Delete author(s), institution(s) or data section(s).

Input example . . .
(1) Data section "Data 6", "Data 7", . . . are renamed as "Data 8", "Data 9"
(2) Then 2 new data sections, named "Data 6" and "Data 7", are added

E1670 - Common Experimental Data - G0 - Netscape

Target

Target Enrichment: [0] % [None]
Chemical Form: [Inconcrete] [Inconcrete]
Physical Form: [Data Input] [None]
Target Thickness: [Inconcrete] mg/cm² [Inconcrete]
Backing: [Self-support] [None]
Backing Thickness: [None] mg/cm² [None]
Target Polarization: [0] % [None]
Target Alignment: [0] % [None]

Accelerator

Accelerator Type and Institute (input from [OCCASMS](#))
1. [University from remote target operator] [University ID from OCCASMS]
Institute: [Inst of Physical and Chemical Res.] [None]
2. [None] [None]
Institute: [None] [None]

Inc. Energy Value: [0] MeV [Lab] [In the middle of the beam]
Inc. Energy Spread: [None] [None] [None]
Inc. Energy Resol.: [R] [Power] [None]
Beam Intensity: [3000] [rev] [None]
Inc. Ion Charge: [None] [None]
Prog. Polarization: [0] % [None]
Ion Source: [None] [None]

Detected Particle and Radiation

Detected Particle and Radiation [guide](#)
Particle Nuclide Radiator Half-Life Time Radiation Energy Abund. Comment

Henkel and Eckert Editor E1670 - Netscape

E1670 - Graph List

Repeat graph [] (input Data you want to plot as "1", "1.2", "1.3", "1.3.4.7.9", . . .) [Reset]

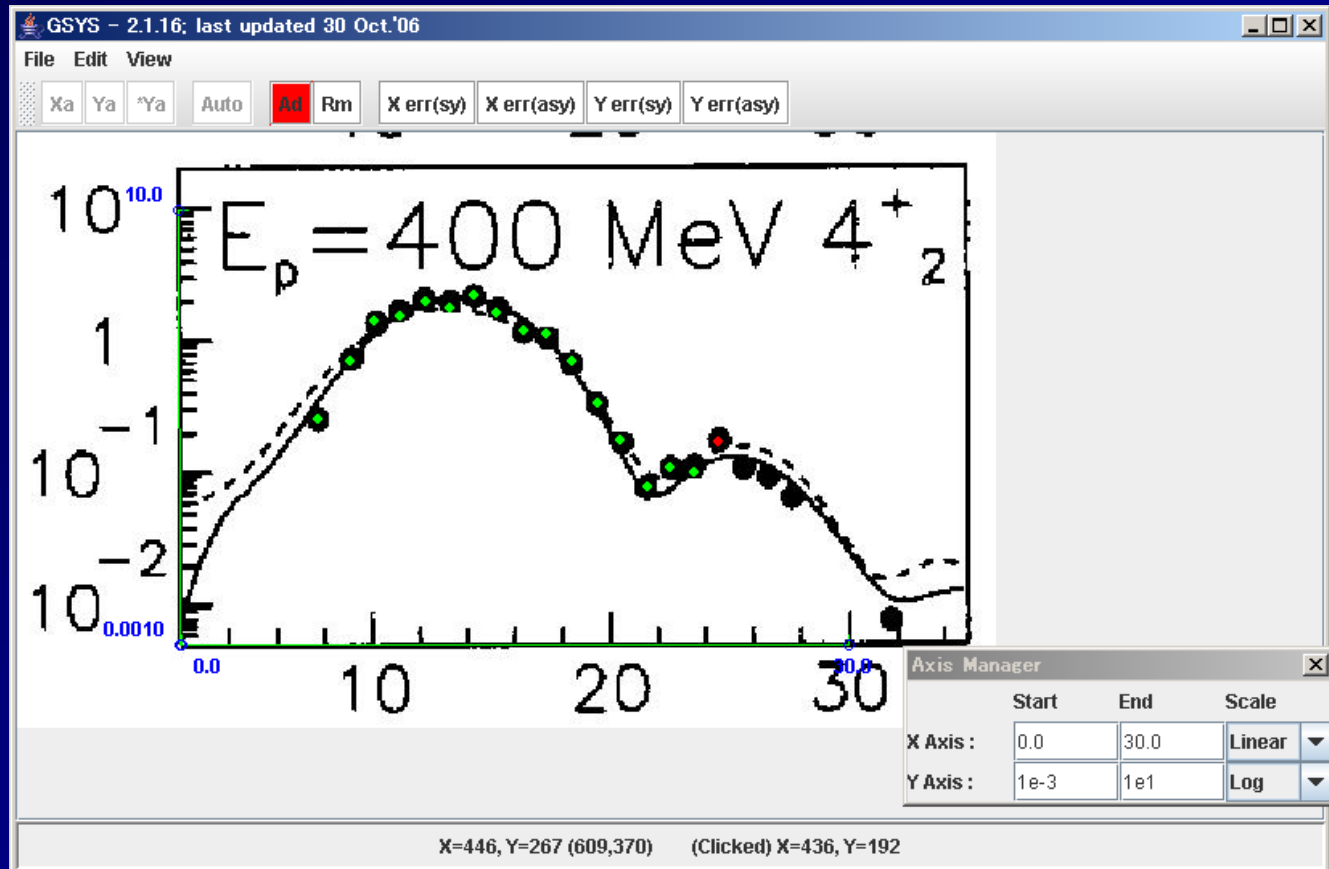
★ Data.1: Fig.2(a), p.112 in reference

Error type: AB, v-linear, y-linear
Data.1 X Y +/- Y_err
Quantity: EVC-ENGY-EVT DSIGMADE DELTA-D
Unit: MEV MBMEV MBMEV

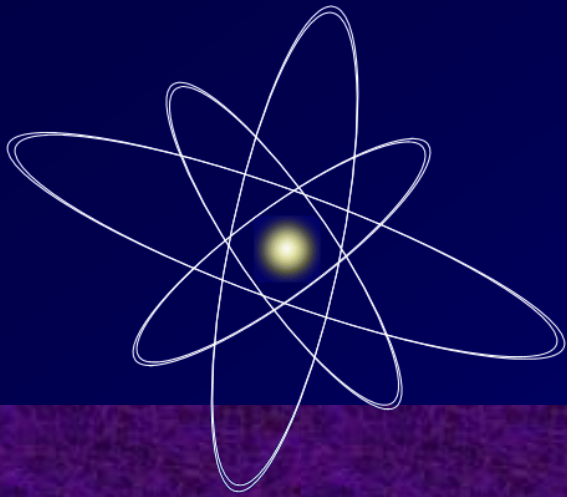
★ Data.2: Fig.2(b), p.112 in reference

Error type: AB, v-linear, y-linear
Data.2 X Y +/- Y_err
Quantity: EVC-ENGY-EVT DSIGMADE DELTA-D
Unit: MEV MBMEV MBMEV

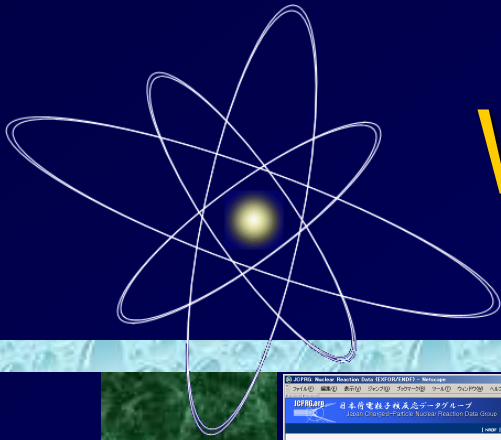
Digitization Software - GSYS



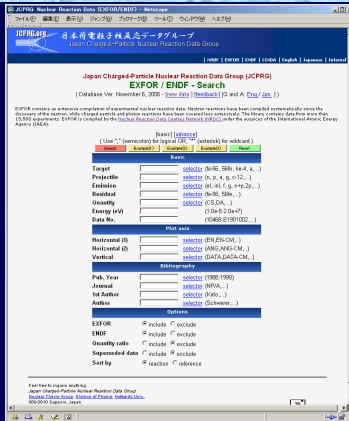
Please download from the JCPRG web site [index-j.html/](#) (Free!)



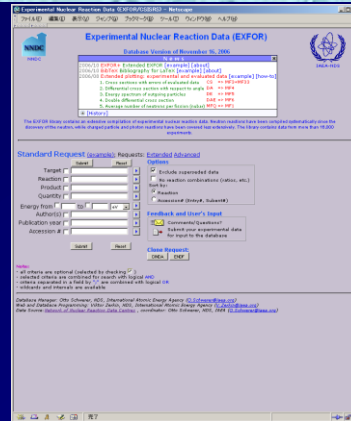
1.3. How to use EXFOR?



Web Service for EXFOR



JCPORG



IAEA-NDS



NNDC



NEA-DB

80,000~90,000 searches / year

<http://www.jcprg.org/index-j.html>

$^{12}\text{C} + ^{12}\text{C}$ reaction cross section

Keywords:

- ◆ Target “C-12”
- ◆ Projectile “C-12”
- ◆ Emission ”NON”
- ◆ Physical quantity “CS”
- ◆ Horizontal axis “EN”
- ◆ Vertical axis “DATA”

NON: Tot – Elastic

ABS: Tot – Elastic - Inelastic

JCPRG: Nuclear Reaction Data (EXFOR/ENDF) - Netscape

日本荷電粒子核反応データグループ
Japan Charged-Particle Nuclear Reaction Data Group

Japan Charged-Particle Nuclear Reaction Data Group (JCPRG)
EXFOR / ENDF - Search
(Database Ver. November 6, 2006 - [new data](#) | [feedback](#) | [Q and A: [Eng](#) / [Jpn](#)])

EXFOR contains an extensive compilation of experimental nuclear reaction data. Neutron reactions have been compiled systematically since the discovery of the neutron, while charged particle and photon reactions have been covered less extensively. The library contains data from more than 15,500 experiments. EXFOR is compiled by the [Nuclear Reaction Data Centre Network \(NRDC\)](#) under the auspices of the International Atomic Energy Agency (IAEA).

[basic] [advance](#)
(Use ";" (semicolon) for logical OR, "*" (asterisk) for wildcard)

Search [Example\(1\)](#) [Example\(2\)](#) [Example\(3\)](#) [Reset](#)

Basic

Target [selector](#) (fe-56, 56fe, he-4, a,...)
Projectile [selector](#) (n, p, a, g, c-12,...)
Emission [selector](#) (el, inl, f, g, n+ β , 2p,...)
Residual [selector](#) (fe-56, 56fe,...)
Quantity [selector](#) (CS, DA,...)
Energy (eV) (1.0e-5, 2.0e+7)
Data No. (10468, E1901002,...)

Plot axis

Horizontal (1) [selector](#) (EN, EN-CM,...)
Horizontal (2) [selector](#) (ANG, ANG-CM,...)
Vertical [selector](#) (DATA, DATA-CM,...)

Bibliography

Pub. Year [selector](#) (1988-1990)
Journal [selector](#) (NPA,...)
1st Author [selector](#) (Kato,...)
Author [selector](#) (Schwerer,...)

Options

EXFOR include exclude
ENDF include exclude
Quantity ratio include exclude
Superseded data include exclude
Sort by reaction reference

Feel free to inquire anything:
Japan Charged-Particle Nuclear Reaction Data Group
Nuclear Theory Group, Division of Physics, Hokkaido Univ.
060-0810, Sapporo, Japan



Search Result

Plot button

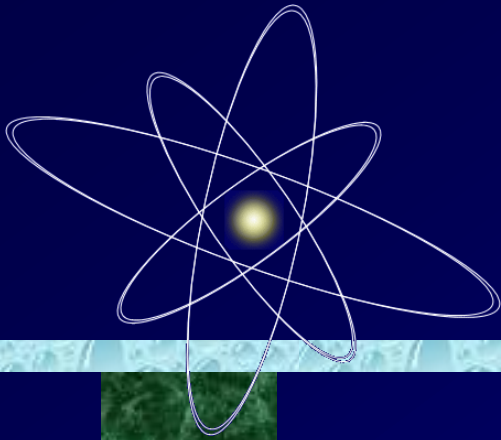
(EXFOR: 0 hits, ENDF: 0 hits)

Plot	Author	Year	Inc. energy (eV)	Work	Type	Reference	Library	Data ID
<input checked="" type="checkbox"/>	6-C-12(6-C-12,NON),,SIG (Cross section)							
<input checked="" type="checkbox"/>	H. Y. Zhang et al.	2002	4.0e+08	4.0e+08	Expt	Jour	Nucl.Phys.A707(2002)303	EXFOR A0715_002
<input checked="" type="checkbox"/>	S. Kox et al.	1985	1.2e+08	2.7e+10	Expt	Jour	Phys.Lett.B159(1985)15	EXFOR 00775_002
<input checked="" type="checkbox"/>	S. Kox et al.	1984	3.6e+08	1.0e+09	Expt	Jour	Nucl.Phys.A420(1984)162	EXFOR 00776_002
<input checked="" type="checkbox"/>	J. Jaros et al.	1978	1.0e+10	2.5e+10	Expt	Jour	Phys.Rev.C18(1978)2273	EXFOR 00744_017
<input checked="" type="checkbox"/>	6-C-0(6-C-12,NON),,SIG (Cross section)							
<input checked="" type="checkbox"/>	T. Zheng et al.	2002	6.9e+06	6.9e+06	Expt	Jour	Nucl.Phys.A709(2002)103	EXFOR E1791_003

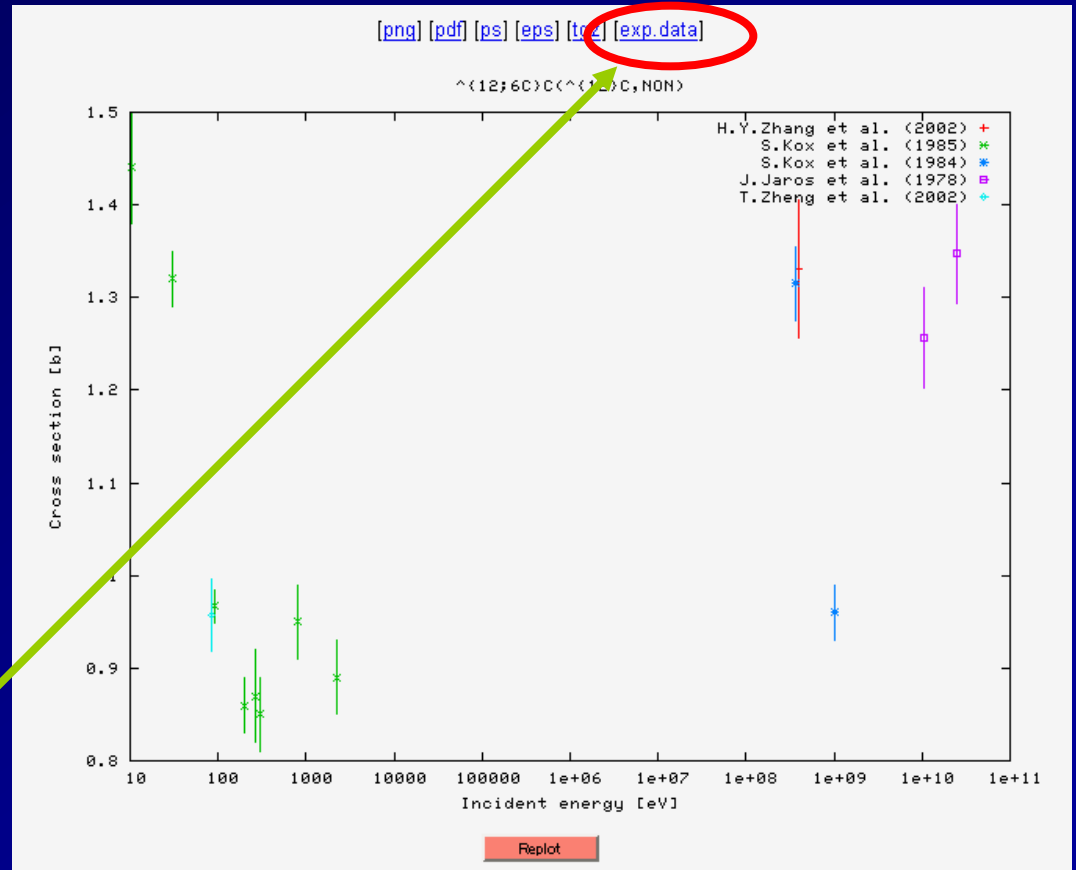
Add your data? (Label)

Link to online journal

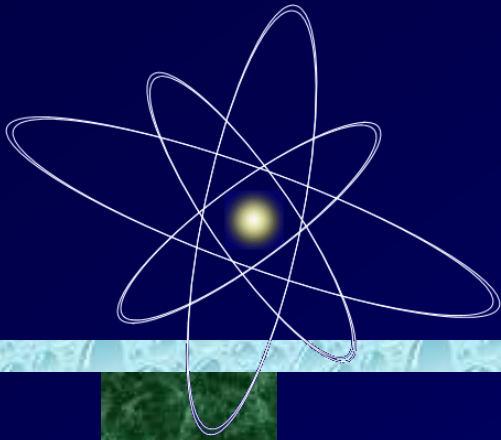
Link to EXFOR source file



Plot (Cross Section)



[Link to numerical data file](#)



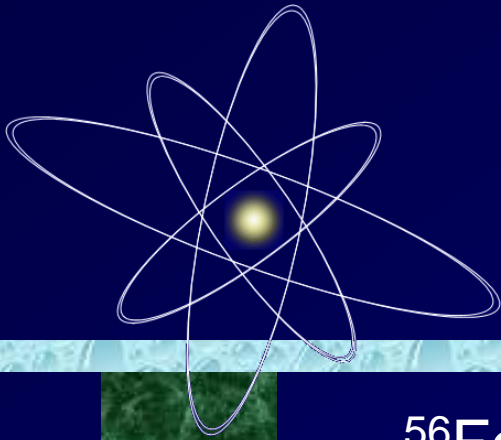
Numerical Data File

```
# Reference: H.Y.Zhang et al. Nucl.Phys.A707(2002)303
# Data ID : A0715002
#           EN           EN           DATA      +DATA-ERR      -DATA-ERR
#           EV           EV           B           B               B
#           3.972000E+08  3.972000E+08  1.331000E+00  7.500000E-02  7.500000E-02
```

```
# Reference: S.Kox et al. Phys.Lett.B159(1985)15
# Data ID : 00775002
#           EN           EN           DATA      +ERR-T          -ERR-T
#           MEV/A        MEV/A        B           B               B
#           1.039000E+01  1.039000E+01  1.440000E+00  6.000000E-02  6.000000E-02
#           3.000000E+01  3.000000E+01  1.320000E+00  3.000000E-02  3.000000E-02
#           9.000000E+01  9.000000E+01  9.670000E-01  1.800000E-02  1.800000E-02
#           2.020000E+02  2.020000E+02  8.600000E-01  3.000000E-02  3.000000E-02
#           2.600000E+02  2.600000E+02  8.700000E-01  5.000000E-02  5.000000E-02
#           3.050000E+02  3.050000E+02  8.500000E-01  4.000000E-02  4.000000E-02
#           8.170000E+02  8.170000E+02  9.500000E-01  4.000000E-02  4.000000E-02
#           2.230000E+03  2.230000E+03  8.900000E-01  4.000000E-02  4.000000E-02
```

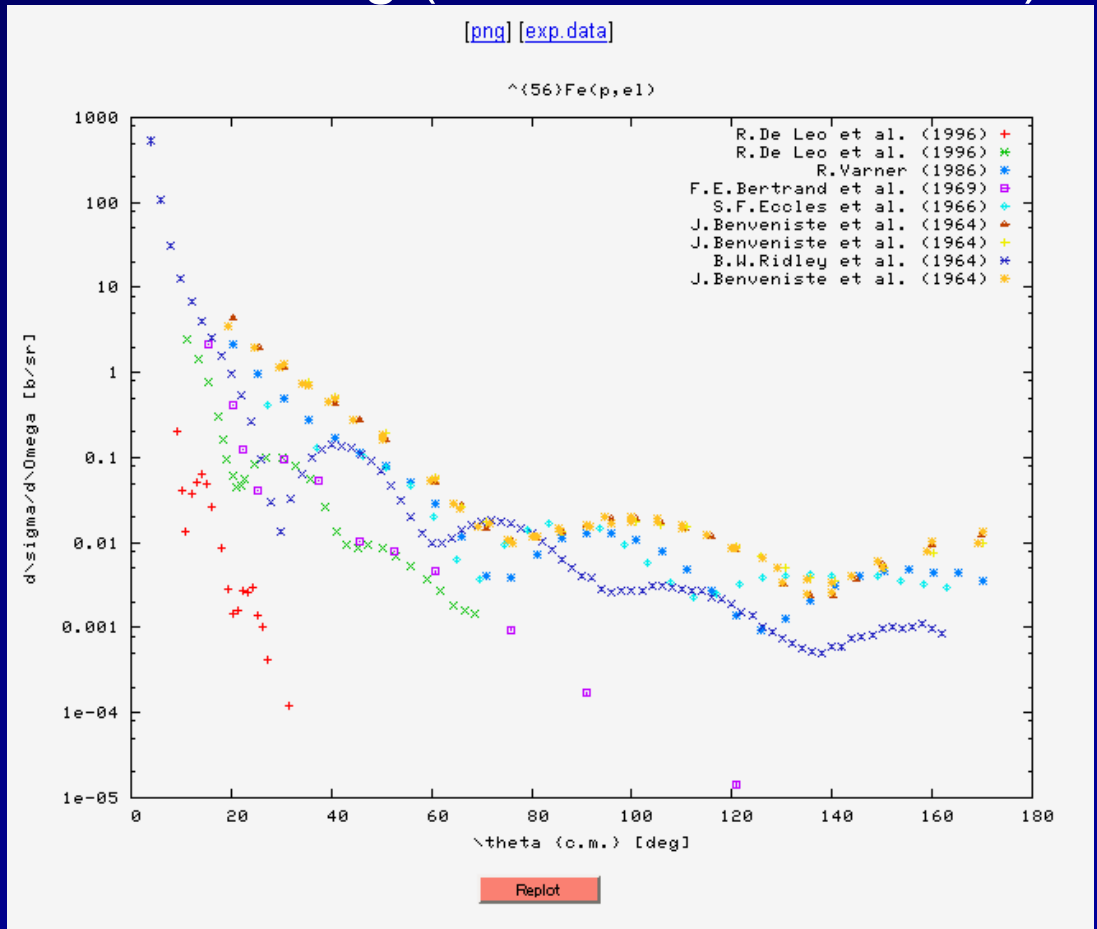
```
# Reference: S.Kox et al. Nucl.Phys.A420(1984)162
# Data ID : 00776002
#           EN           EN           DATA      +DATA-ERR      -DATA-ERR
#           EV           EV           B           B               B
#           3.600000E+08  3.600000E+08  1.315000E+00  4.000000E-02  4.000000E-02
#           9.960000E+08  9.960000E+08  9.600000E-01  3.000000E-02  3.000000E-02
```

```
# Reference: J.Jaros et al. Phys.Rev.C18(1978)2273
```



Plot ($d\sigma/d\Omega$)

$^{56}\text{Fe} + p$ elastic scattering (100 MeV ~ 700 MeV)



Do we want co-operation in data dissemination?

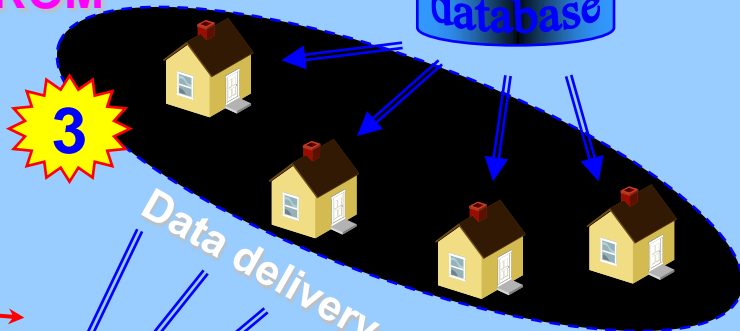
NRDC Centres



- Co-operation:**
- Common formats
 - Common tools
 - Common efforts
 - Common result: **good and rational**

from publication to user
via EXFOR

Service via Web,
CD-ROM



Our problem:
~35% of all data can be presented **ONLY** in EXFOR format !!!

- Co-operation ?**
- Common formats ? **No**
 - Common tools ? **No**
 - Co-ordination ? **No**
 - Good result ? **?**



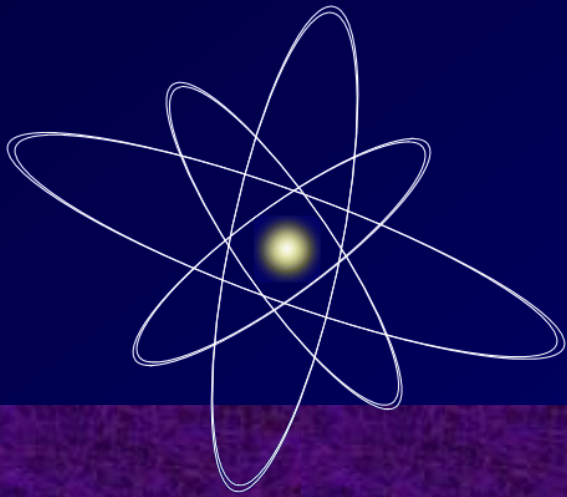
We want Happy Users

- Output:**
- data
 - bibliography
 - plots

Output formats:

- EXFOR 100%
- C4 ~65%
- Table ~40%
- X4+ 100%
- T4 ~40%
- R33 ~15%
- BibTeX 100%
- GIF, PS ~60%
- other





2.2. Evaluation of Nuclear Reaction Data



Evaluation of Low Energy Nuclear Reaction Data

Astrophysical Nuclear reactions

Graduate School of “Cosmo Sciences”

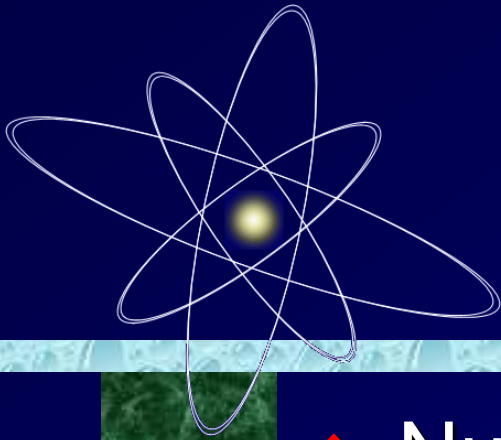
in Hokkaido University from 2006

Light Nuclei (NACRE)

Nuclear reactions of Light nuclei

Collaboration with the Group of

Astrophysics



Evaluations

◆ Nuclear Reactions of Light Nuclei

1) NRDF/A (2006)

C – Mg 31 Reactions

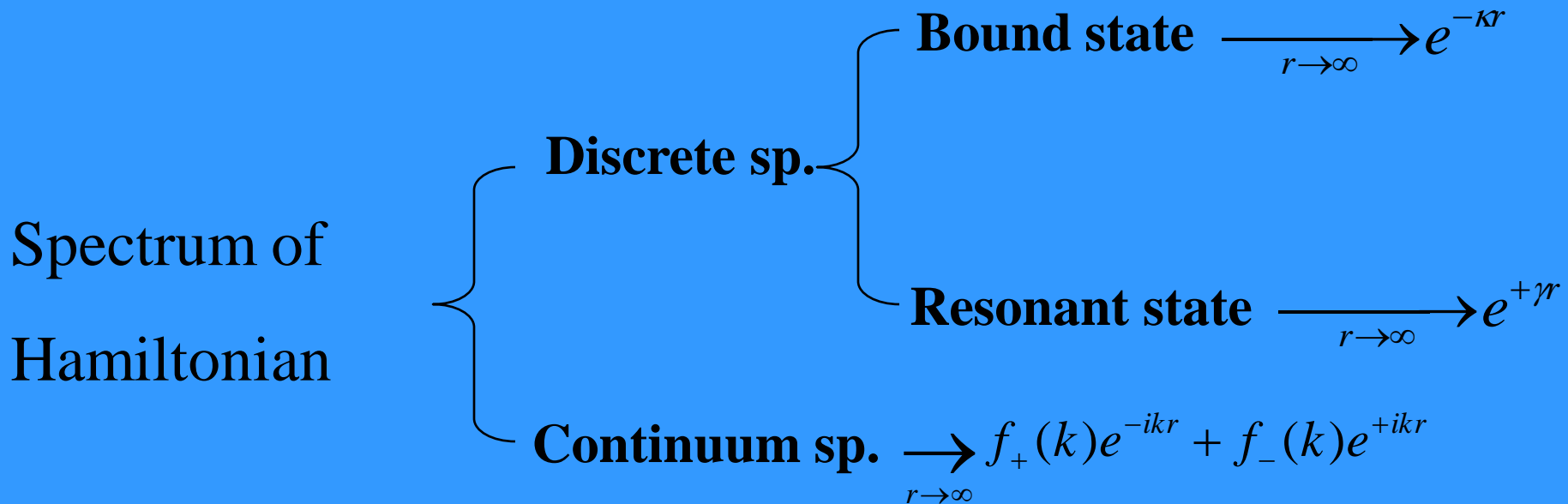
<http://www.jcprg.org/index-j.html>

2) NRDF/A (2008)

H – Si 284 Reactions

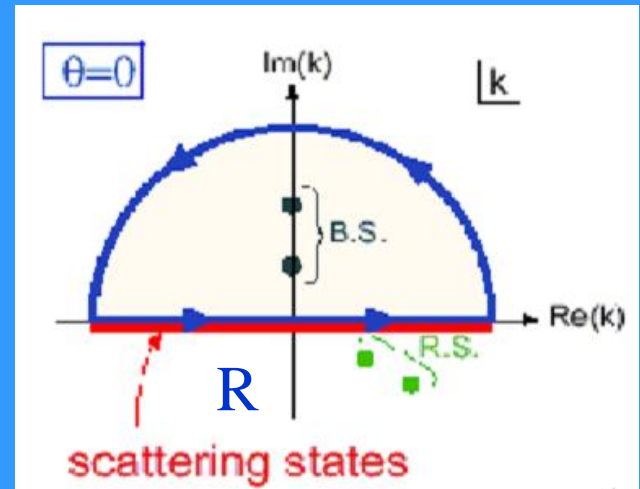
NRDF/A: table

Resolution of Identity in the complex scaling method

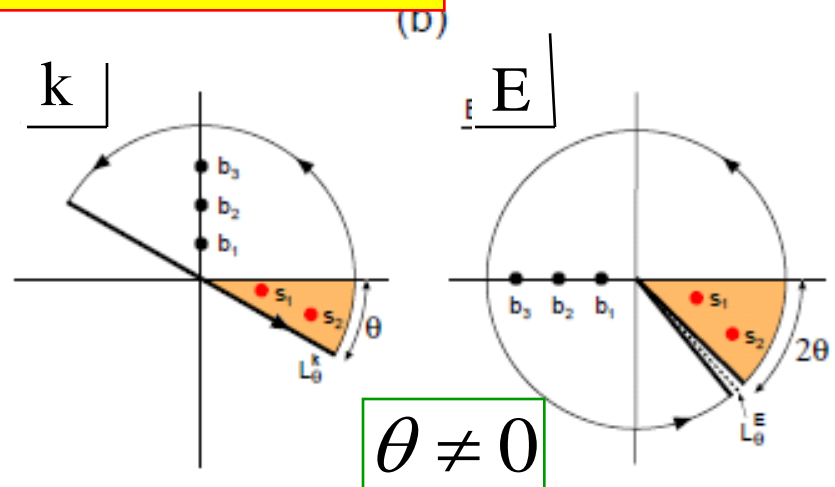
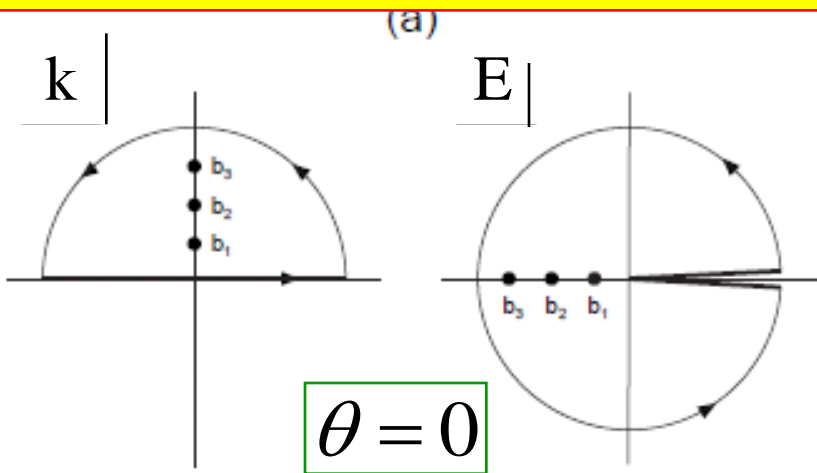


Completeness Relation (Resolution of Identity)

$$1 = \sum_{n=b} |u_n\rangle \langle \tilde{u}_n| + \frac{1}{\pi} \int_R dk |\psi_k\rangle \langle \tilde{\psi}_k|$$

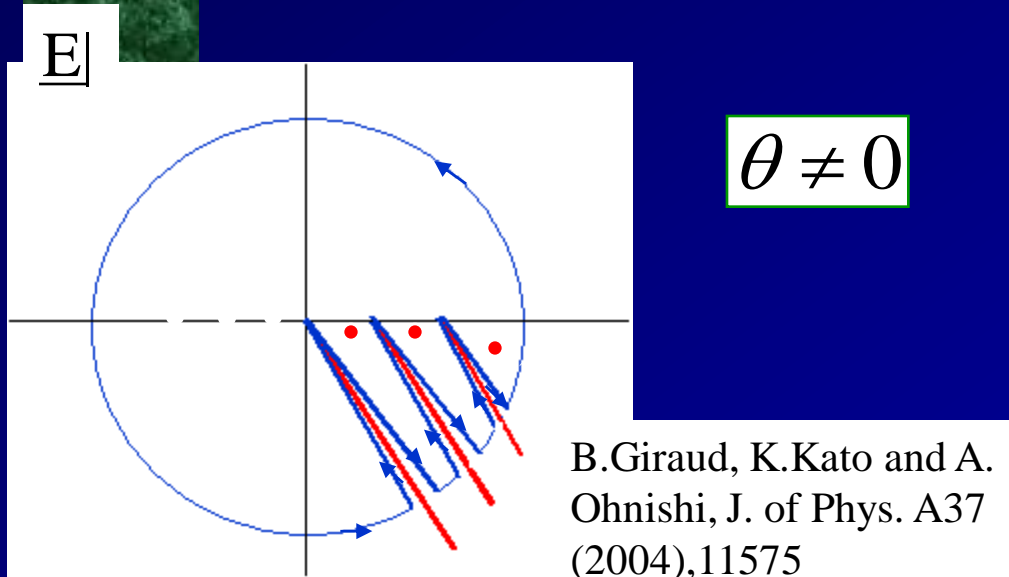


Resolution of Identity in Complex Scaling Method



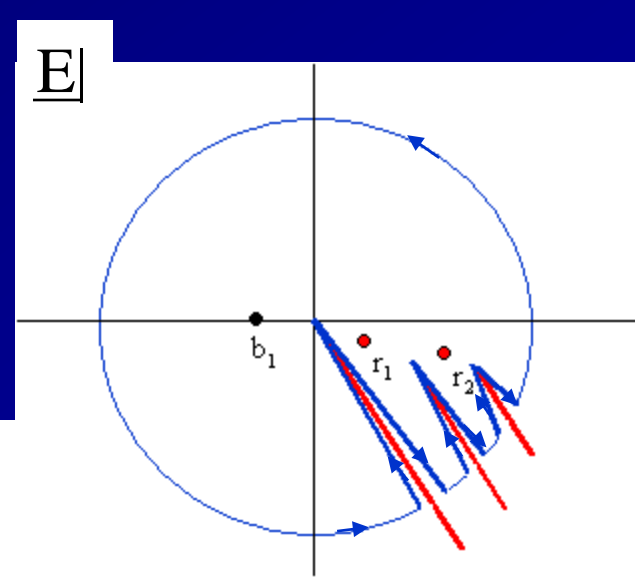
Single Channel system

B.Giraud and K.Kato, Ann.of Phys. 308 (2003), 115.



B.Giraud, K.Kato and A. Ohnishi, J. of Phys. A37 (2004), 11575

Coupled Channel system



Three-body system

Description of unbound states in the Complex Scaling Method

$$(H_0 + V)\Psi = E\Psi$$

$$H_0 = T + V_C$$

V ; Short Range Interaction

$$H_0\Psi_0 = E\Psi_0$$

(Ψ_0 ; regular at origin)

Solutions of Lippmann-Schwinger Equation

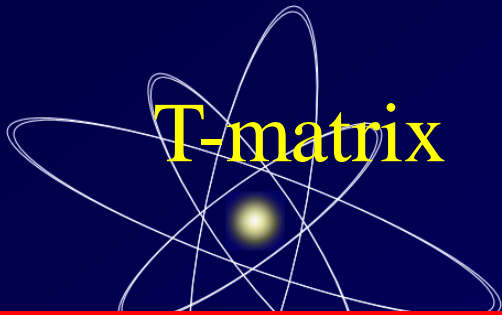
$$\Psi = \Psi_0 + \frac{1}{E - H + i\varepsilon} V\Psi_0$$

Outgoing
waves

Complex
Scaling

$$\Psi^{(+)} = \Psi_0 + \frac{1}{E - H(\theta)} V\Psi_0$$

A. Kruppa, R. Suzuki and K. Kato,
phys. Rev.C75 (2007), 044602



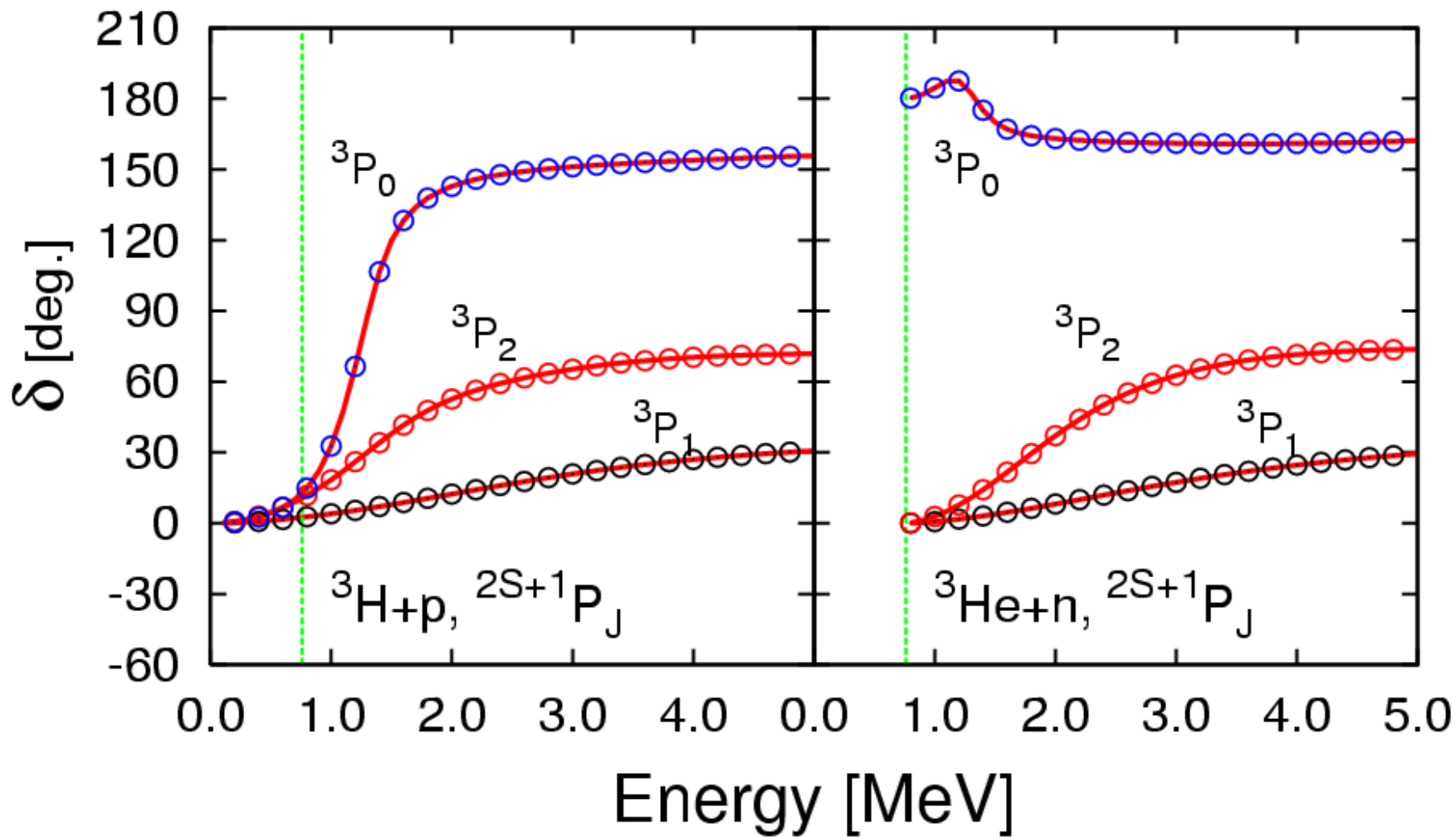
T-matrix

$T_1(k)$

$$T_l = \langle \Psi_0 | V | \Psi^{(+)} \rangle$$

$$= \langle \Psi_0 | V | \Psi_0 \rangle + \langle \Psi_0 | V U(\theta)^{-1} \frac{1}{E - H(\theta)} U(\theta) V | \Psi_0 \rangle$$

$$= \langle \Psi_0 | V | \Psi_0 \rangle + \sum_{n=1}^N \langle \Psi_0 | V U(\theta)^{-1} \frac{|\Phi_n^\theta\rangle \langle \Phi_n^\theta|}{E - E_n(\theta)} U(\theta) V | \Psi_0 \rangle$$



• Lines : Runge-Kutta method
 • Circles : CSM+Base

Complex-scaled Lippmann-Schwinger Eq.



- CSLM solution

$$|\Psi^+(k, K)\rangle = |k, K\rangle + \sum_i U^{-1} |\phi_i^\theta\rangle \frac{1}{E - E_i^\theta} \langle \phi_i^\theta | U \hat{V} | k, K \rangle$$

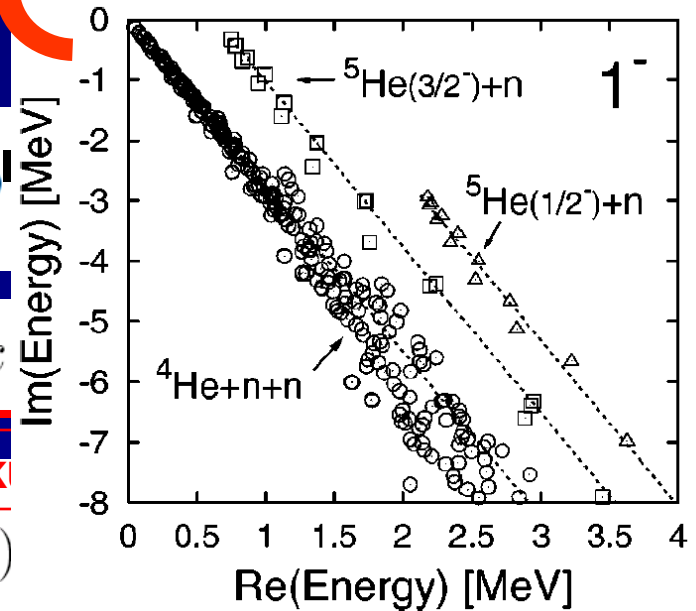
- B(E1) Strength

$$\frac{d^6 B(E1)}{dkdK} = |\langle \Psi^+(k, K) | \hat{O} | \Phi_{g.s.} \rangle|^2$$

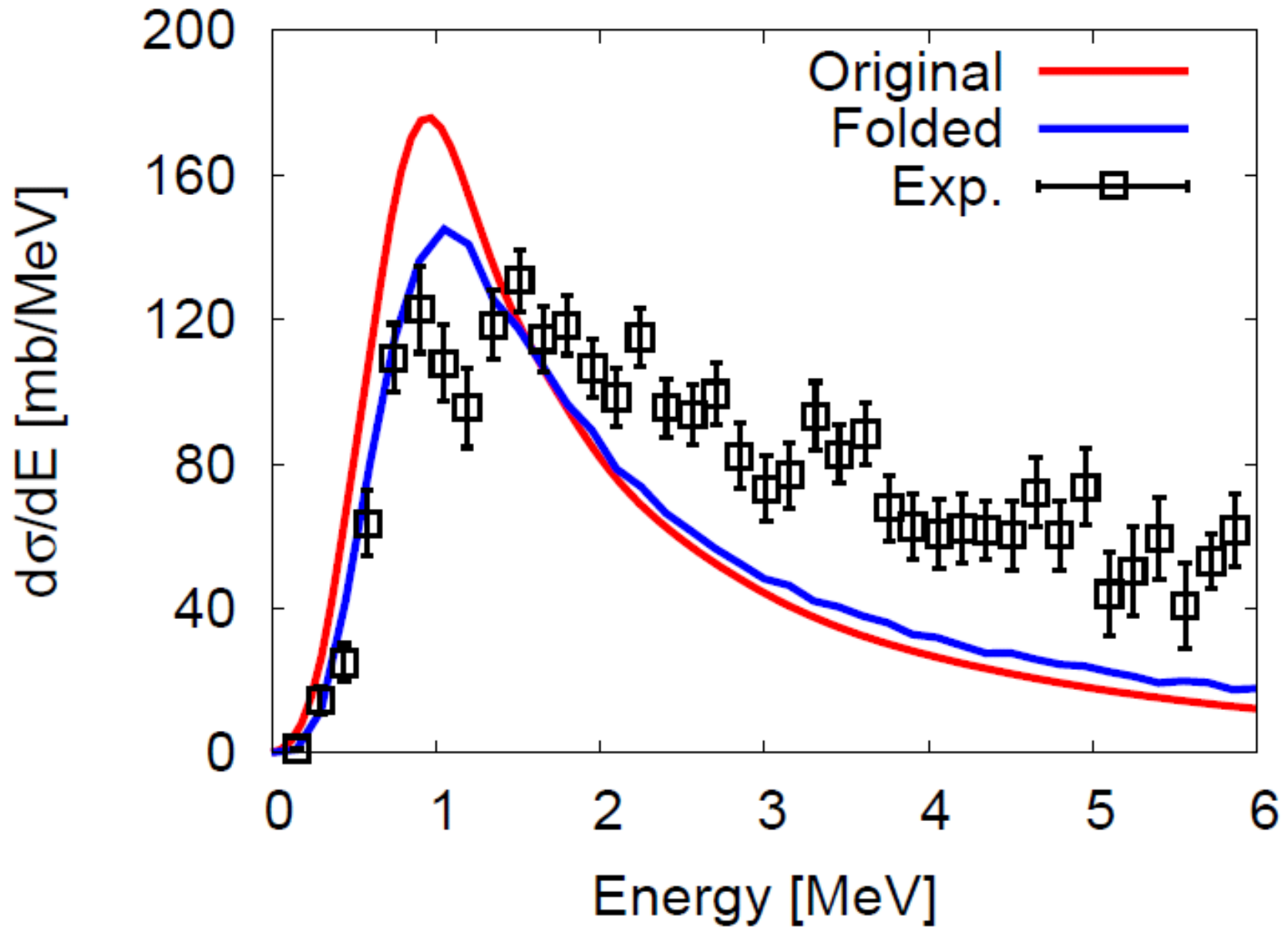
$$\langle \Phi_{g.s.} | \hat{O}(E1) | \Psi^+(k, K) \rangle = \langle \Phi_{g.s.} | \hat{O}(E1) | k \rangle$$

Direct break

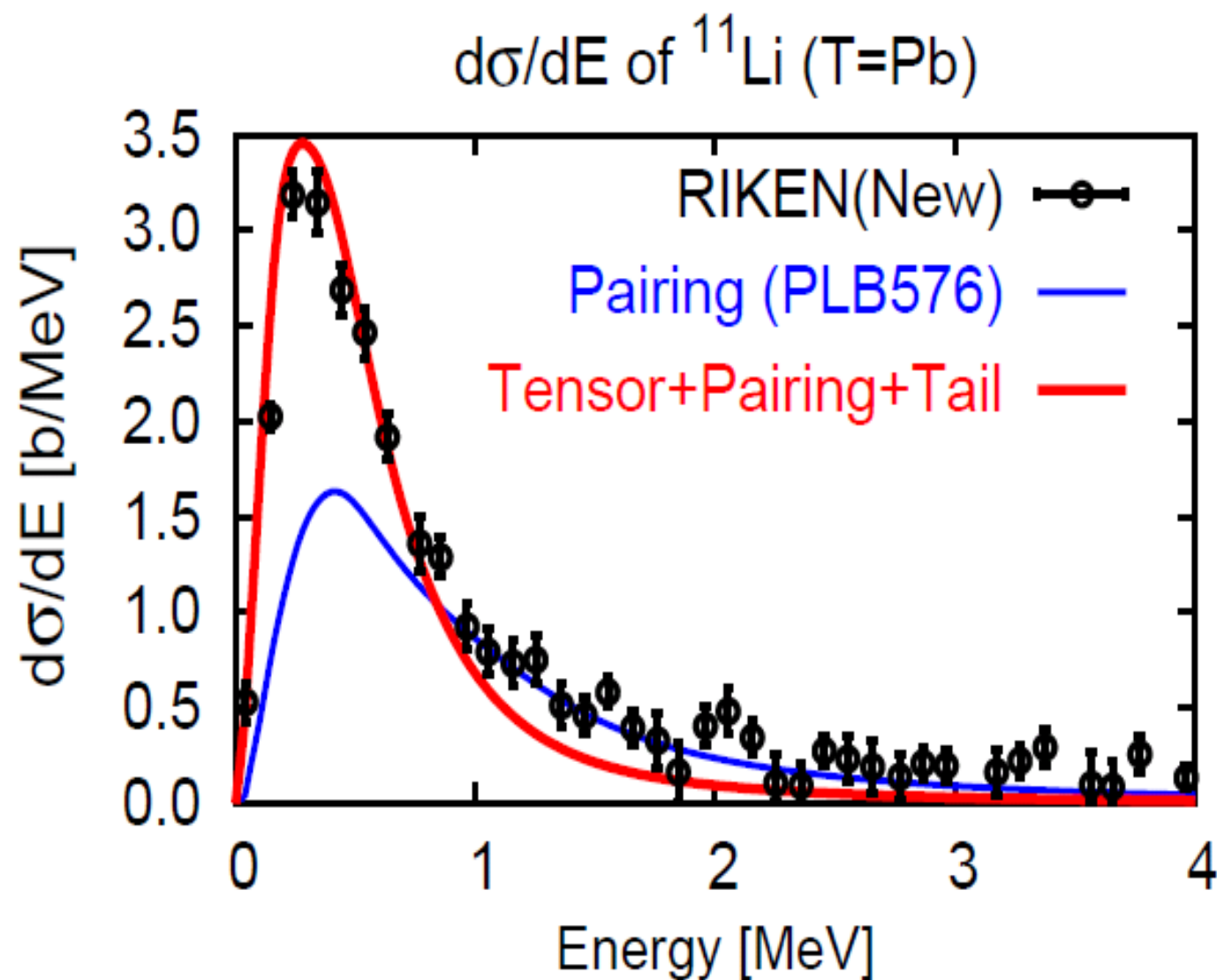
$$+ \sum_i \langle \Phi_{g.s.} | \hat{O}(E1) | \phi_i^\theta \rangle \frac{1}{E - E_i^\theta} \langle \phi_i^\theta | U \hat{V} | k, K \rangle$$



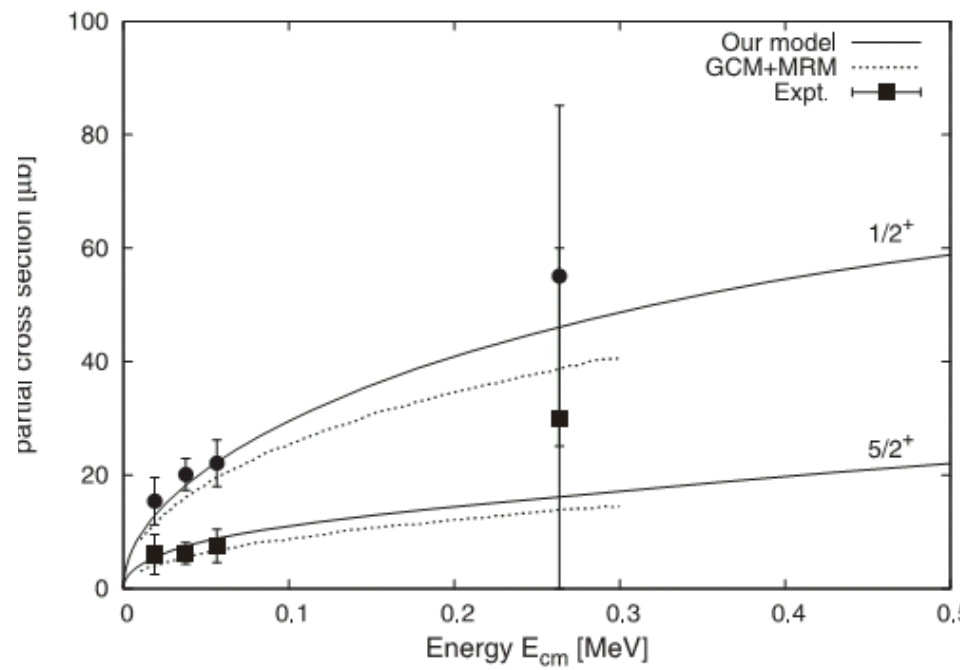
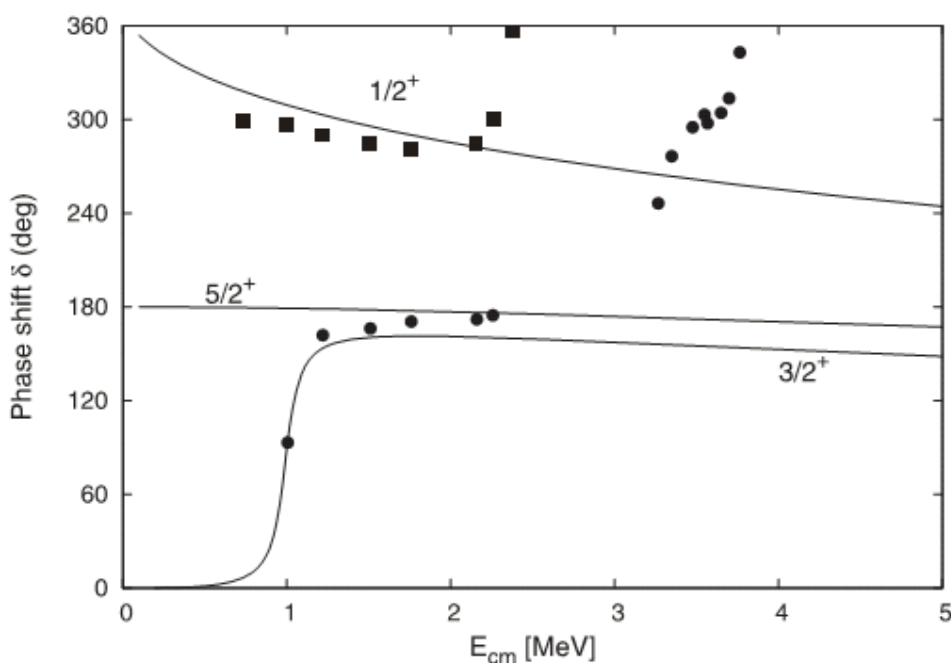
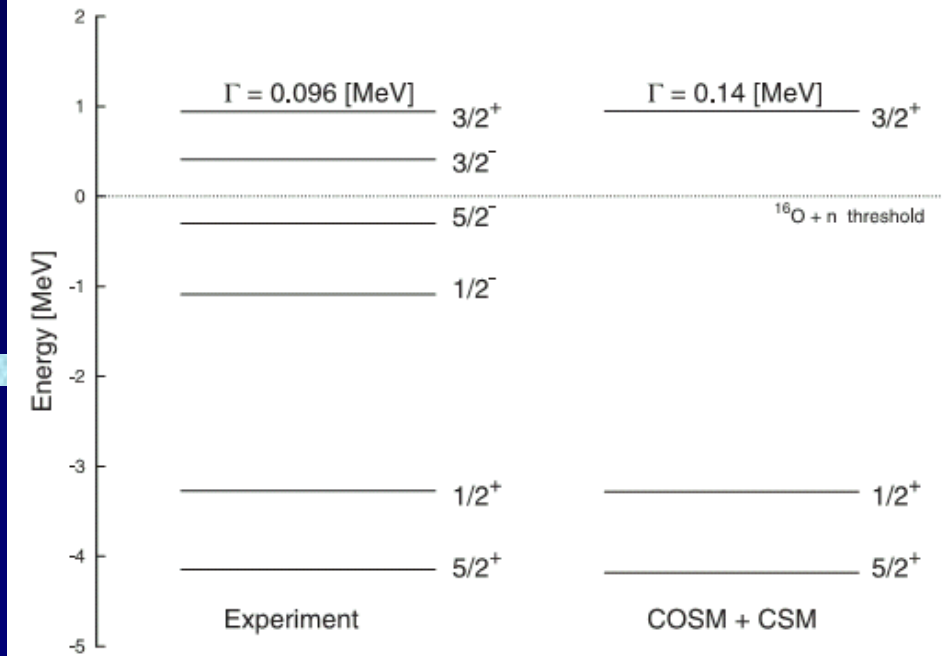
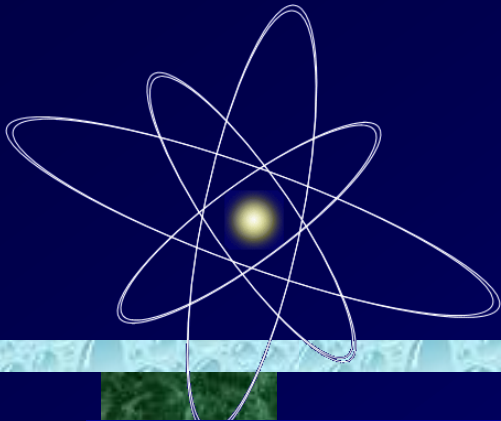
Final state interaction (FSI)

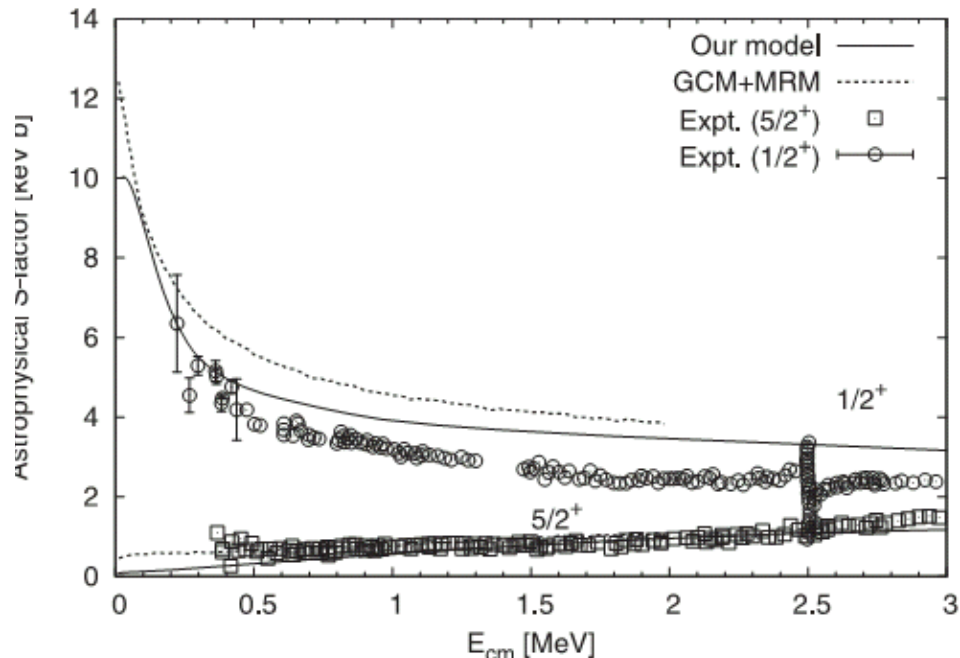
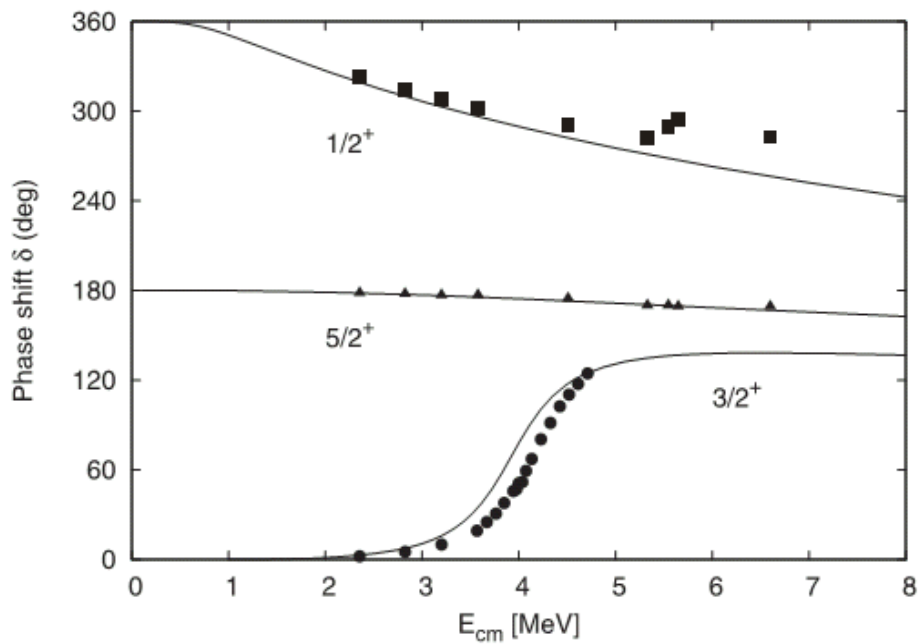
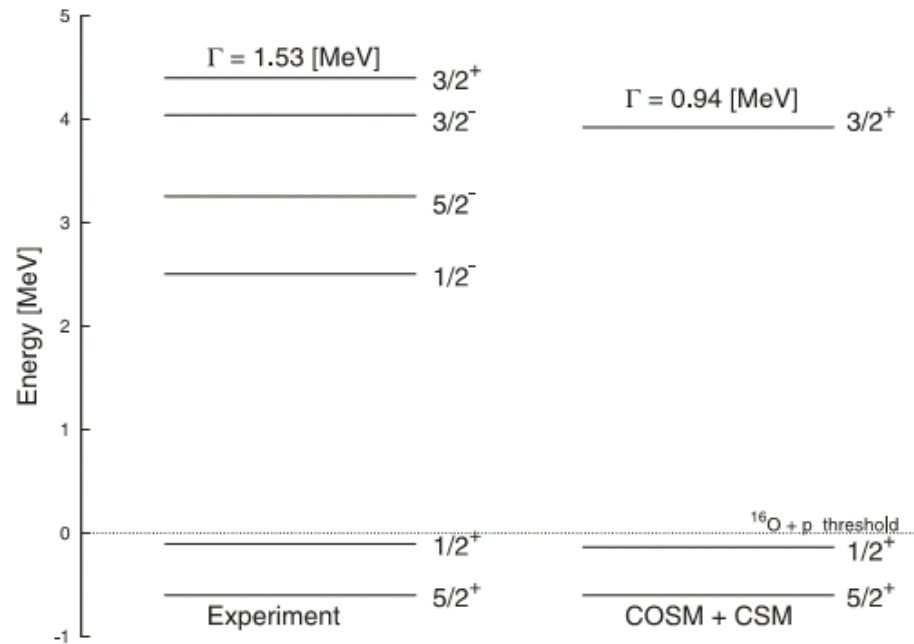
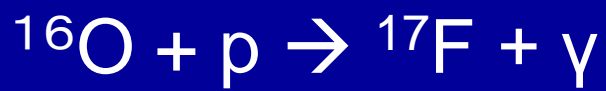
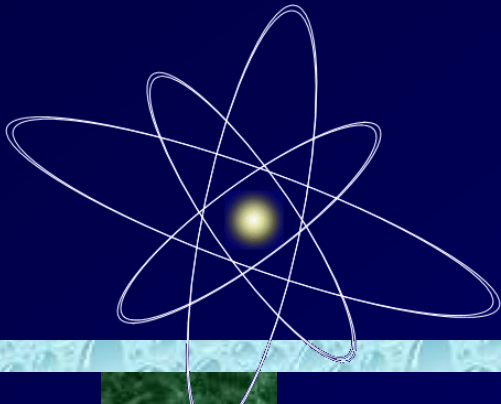


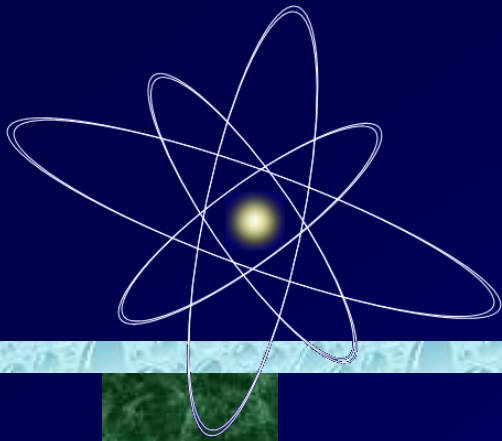
Comparison to RIKEN New data (Nakamura et al.,RIKEN Accel.Prog.Rep.38).



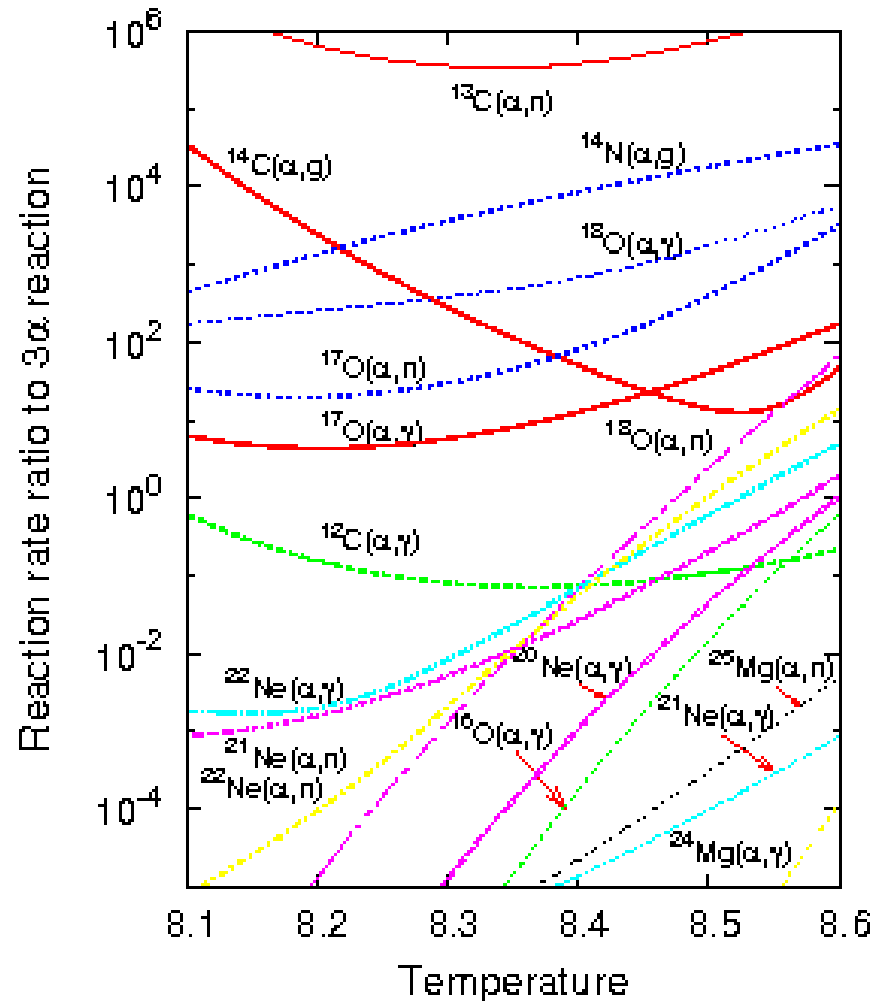
○ Preliminary. We can see a good agreement.

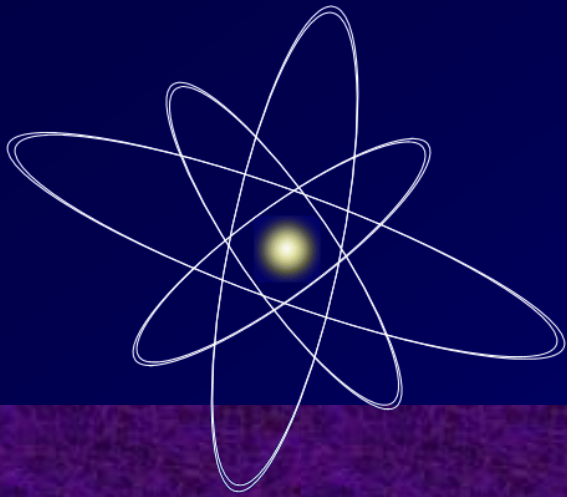




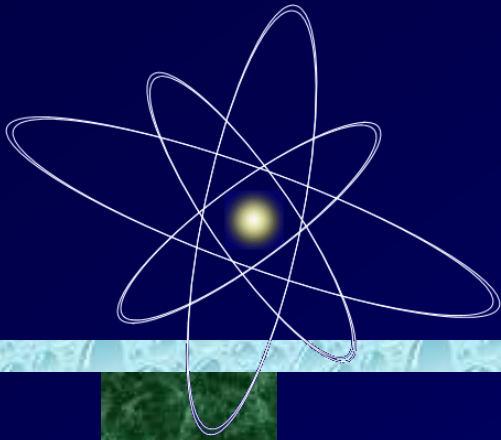


Nuclear Cluster Studies



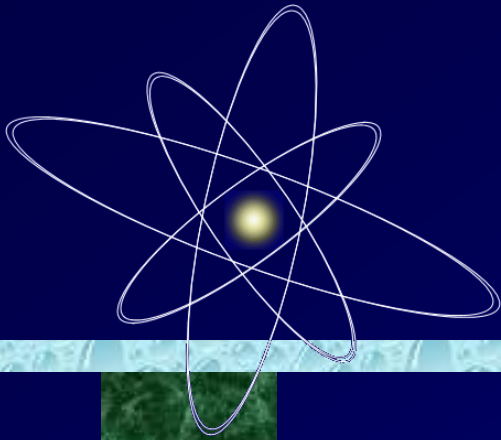


2.3.1. Accelerator facility of Asian countries



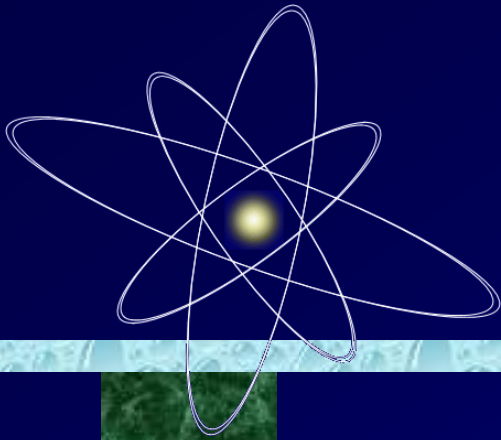
Asian Nuclear Experiment Facilities: China

- ◆ China Institute of Atomic Energy, DNP, Beijing
Beijing Tandem Acc. Lab.
- ◆ Chinese Academy of Sciences, IMP, Lanzhou
HIRFL
- ◆ Chinese Academy of Sciences, SIAP, Shanghai
SLEGS (in planning)



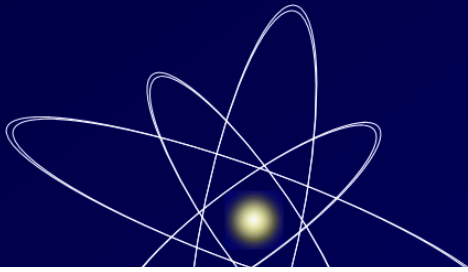
Asian Nuclear Experiment Facilities: India

- ◆ New Delhi University Grants Commission of India,
New Delhi
Inter-University Accelerator Center
- ◆ Variable Energy Cyclotron Center, Kolkata
VECC



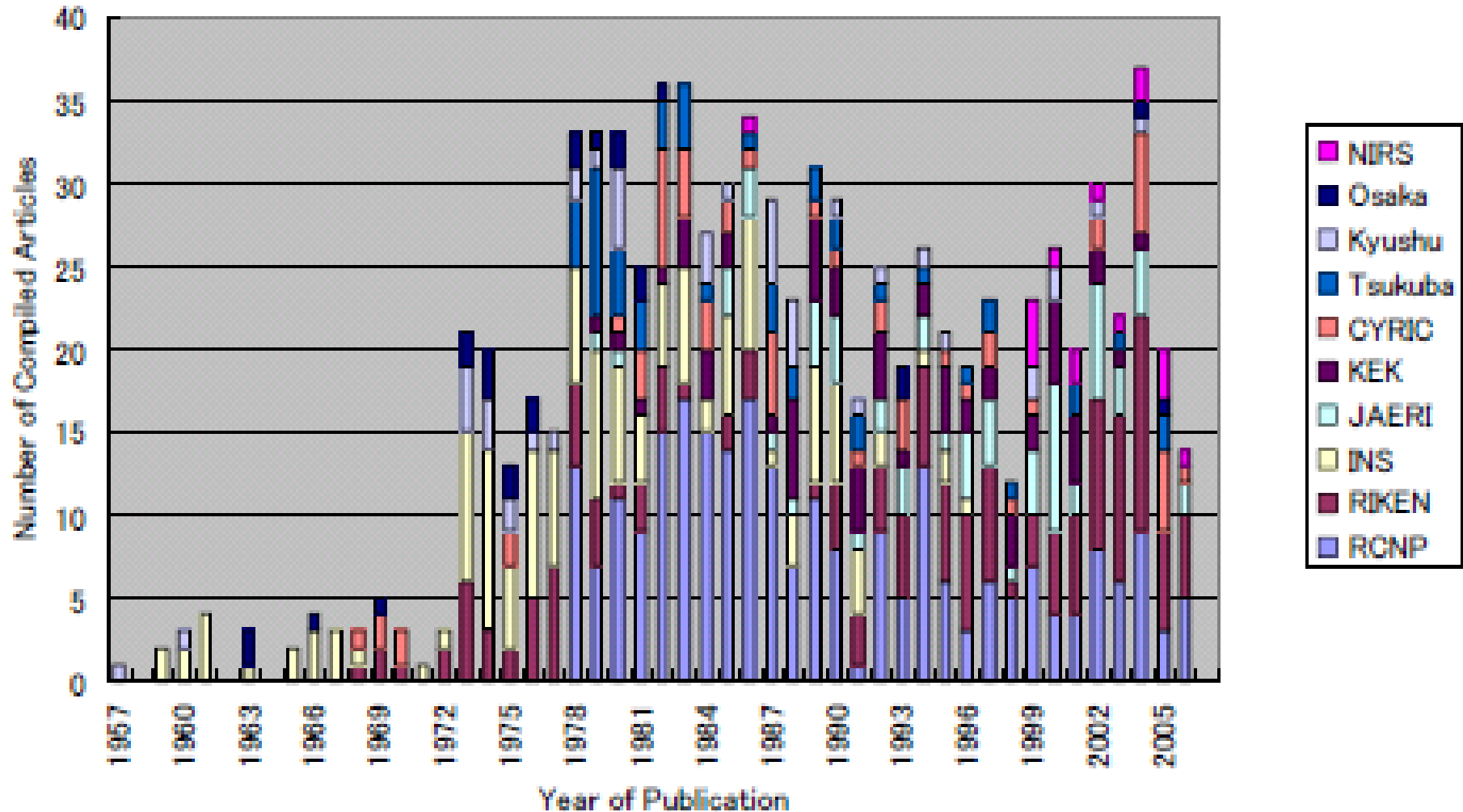
Asian Nuclear Experiment Facilities: Korea

- ◆ Korea Institute of Geoscience and Mineral Resources, Daejeon
Ion Beam Application Group (Tandems)
- ◆ National Cancer Centre, Goyang
Center for Application Group (Cyclotron)
- ◆ National Centre for Inter-Universities Research Facility, Seoul
Electrost. Ion Acc./AMS Fac. (Tandem)



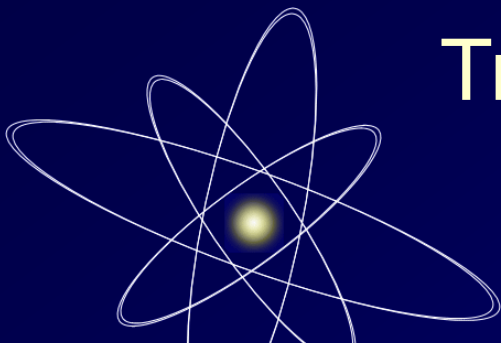
Asian Nuclear Experiment Facilities: Japan

Compilation Statistics (Japan, CPND)



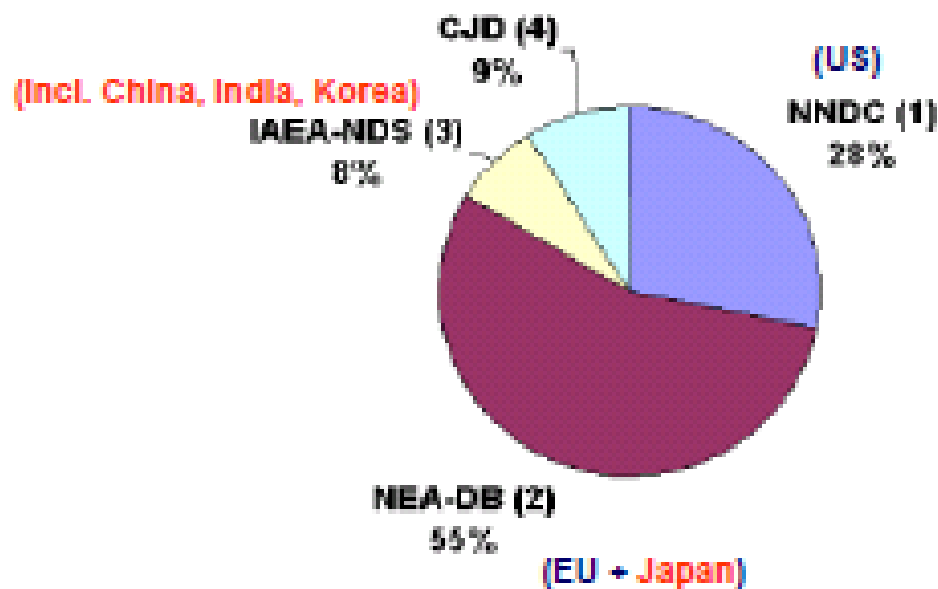


2.3. Proposal of Asian Nuclear Data Collaboration

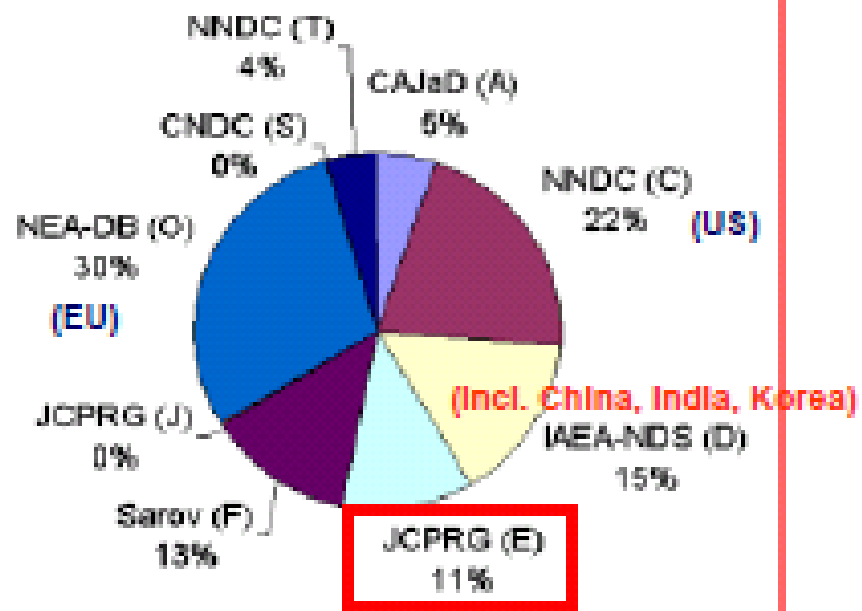


Tri-Polar Structure of Data Production (US, Europe, Asia)

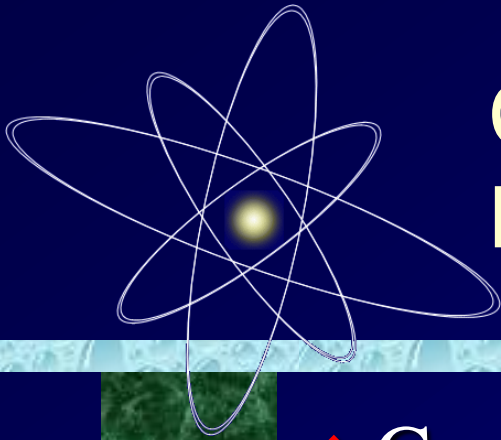
Compilation Statistics (Neutron)



Compilation Statistics (CFND)

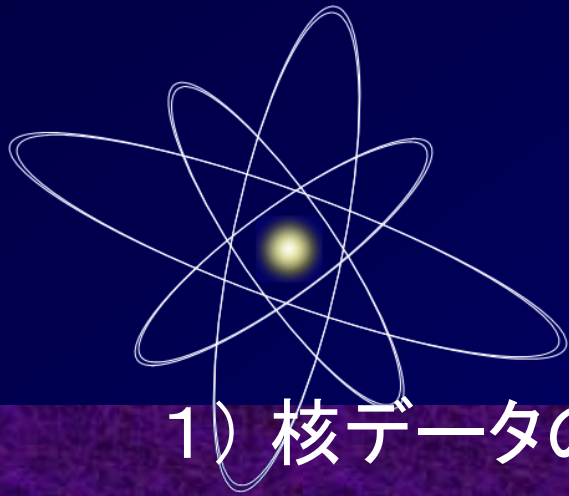


- USA → National Nuclear Data Center (NNDC)
- Europe → OECD NEA Data Bank (NEA-DB)
- Asia → ??



Collaboration in Asian Countries for Nuclear Reaction Database

- ◆ Compilation of data from their own countries with assistance from JCPRG
- ◆ Training and /or workshop of compilation
- ◆ JCPRG and IAEA-NDS can offer compilers software for data compilation (free of charge)



3. Summary

- 1) 核データの重要性についての理解、認識が高くなってきている。
- 2) 世界初の実験データを人類の知的財産とする責任がある。
- 3) 評価可能な実験データ。
- 4) 北大核反応データセンターの3つの課題。
- 5) この分野の専門的研究者の必要性。