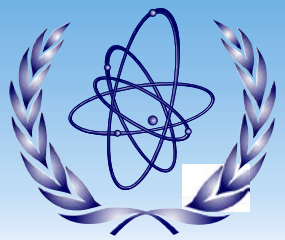


International Atomic Energy Agency

AASPP Workshop

The 2nd Asian Nuclear Reaction Database Development Workshop

Beijing Phoenix Palace Hotel, Beijing, China

5–9 September 2011

Introduction to EXFOR

Naohiko OTSUKA

（大塚直彦）

Nuclear Data Section

Department of Nuclear Sciences and Applications

Outline

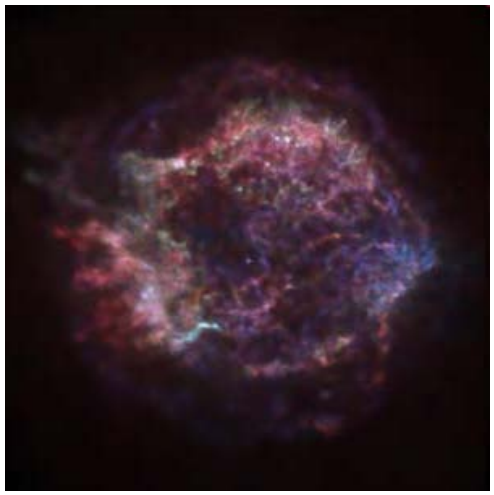
- Why nuclear data?
- Nuclear database
- Nuclear reaction data centres (NRDC)
- EXFOR
- EXFOR modern application
- EXFOR compilation
- Asian name in EXFOR
- Summary

Nuclear Reaction Network in Science

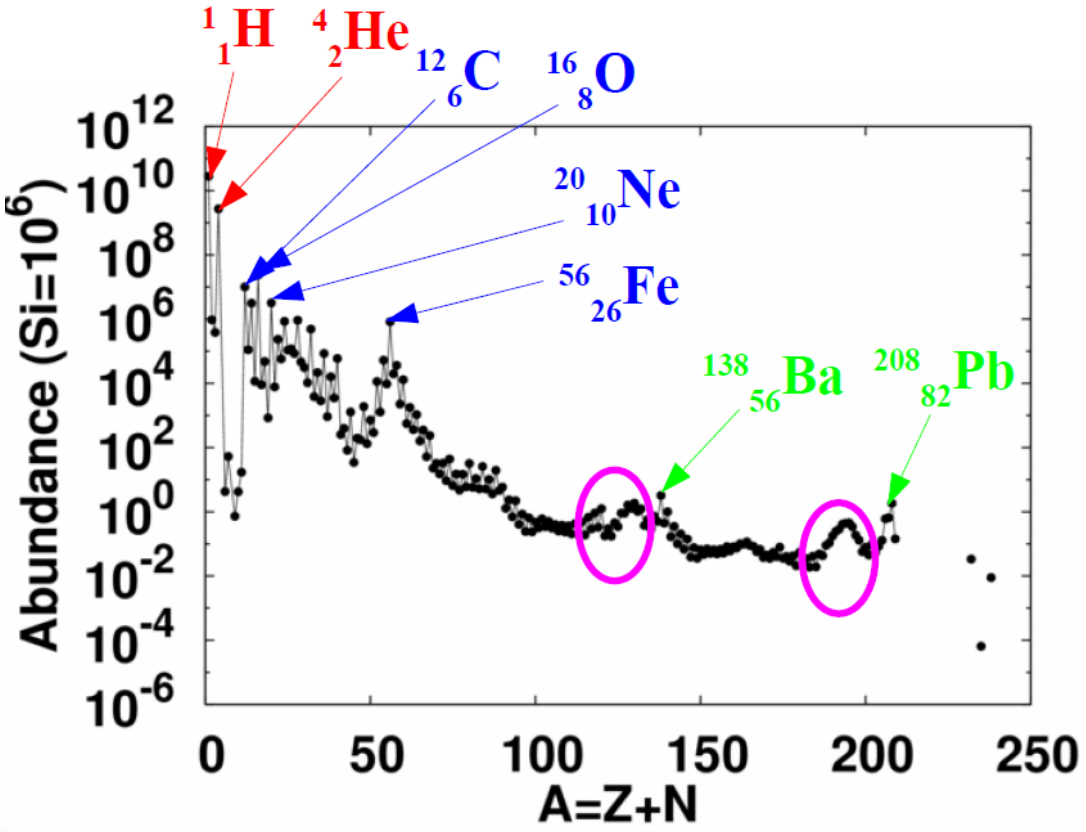
Nucleosynthesis

How do we understand isotopic abundances?

Isotopic abundances in the universe

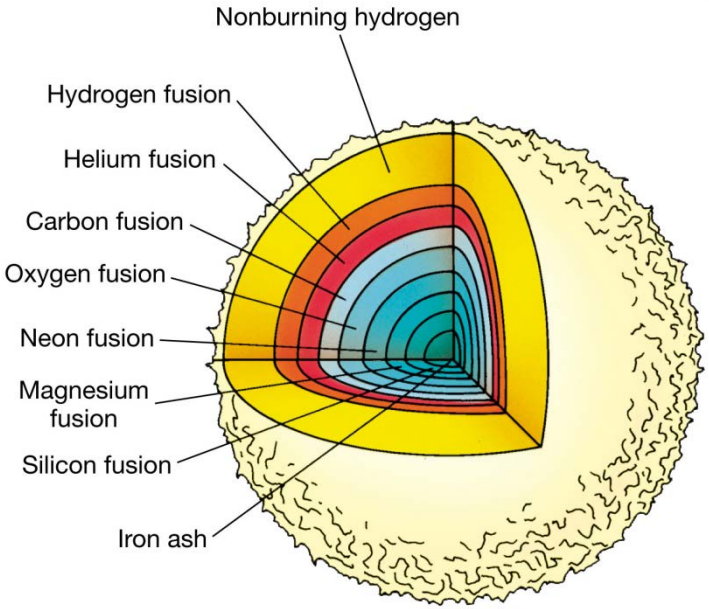


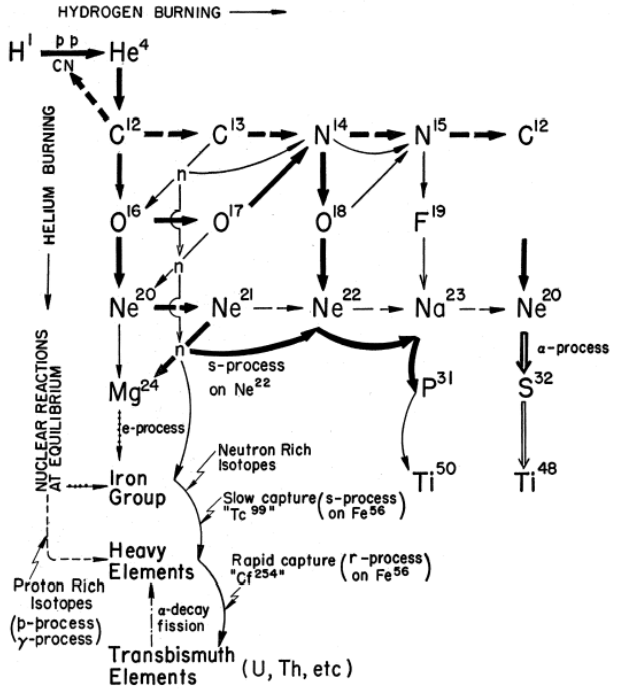
Cassiopeia A (Cas A).
Source: Chandra X-ray Observatory, NASA/CXC/SAO/Rutgers/J.Hughes



Nuclear Reaction Network in Science (cont)

Nuclear reaction network in high mass stars





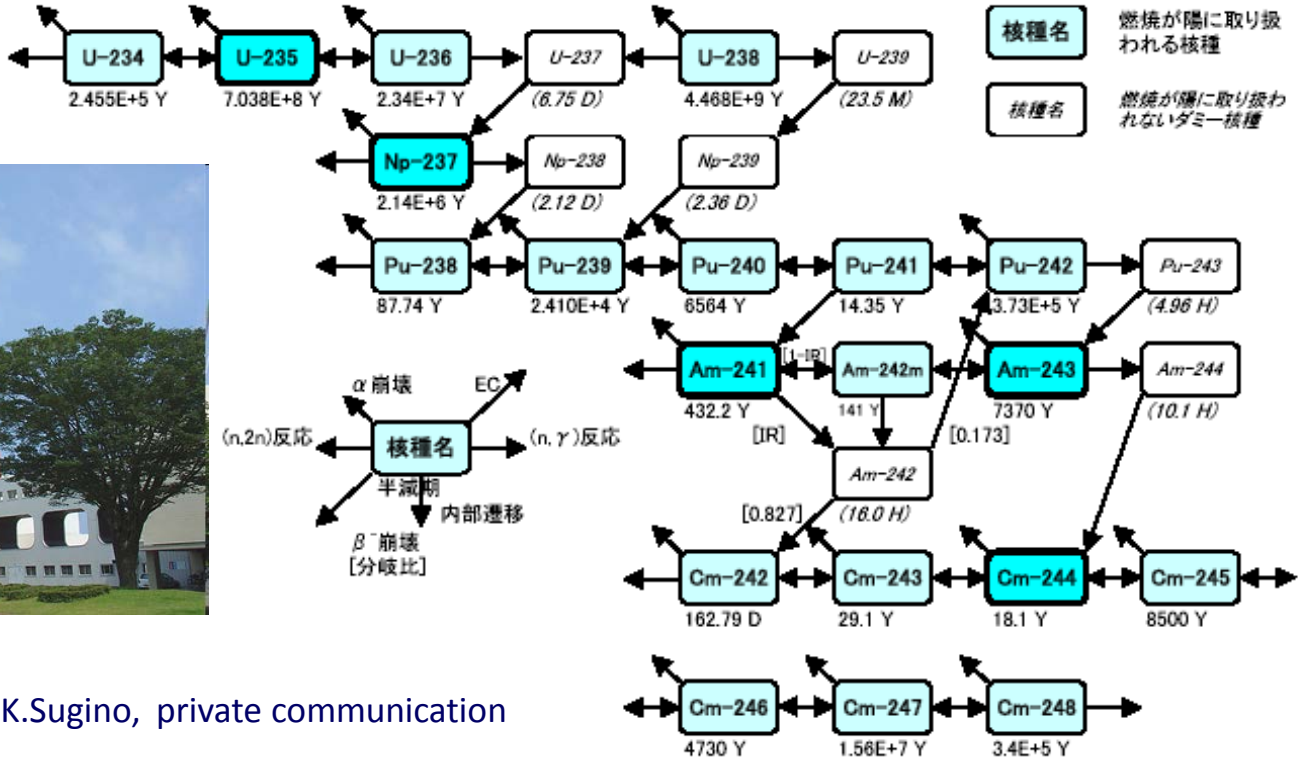
E. M. Burbidge et al., (B^2FH) Rev.Mod.Phys.29(1957)

(Note: Heavy elements are also created in supernovae.)

Nuclear Reaction Network in Application

Another example of reaction network:

Burning chain model in a fast reactor (*JOYO*, Japan)



K.Sugino, private communication

Nuclear Data in Nuclear System

Growth of the number of the *i*-th isotope per unit time/volume $N_i(t)$

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

Increase by reaction from the i-th isotope

Increase by decay into the i-th isotope

Decrease by reaction from the i-th isotope

Decrease by decay of the i-th isotope

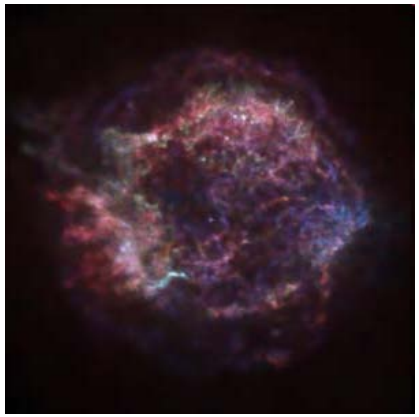
Various nuclear data (λ, σ) for each isotope as input parameters!

Nuclear Data in Science and Technology

Science

- Nuclear physics
- Astrophysics

etc.



Technology

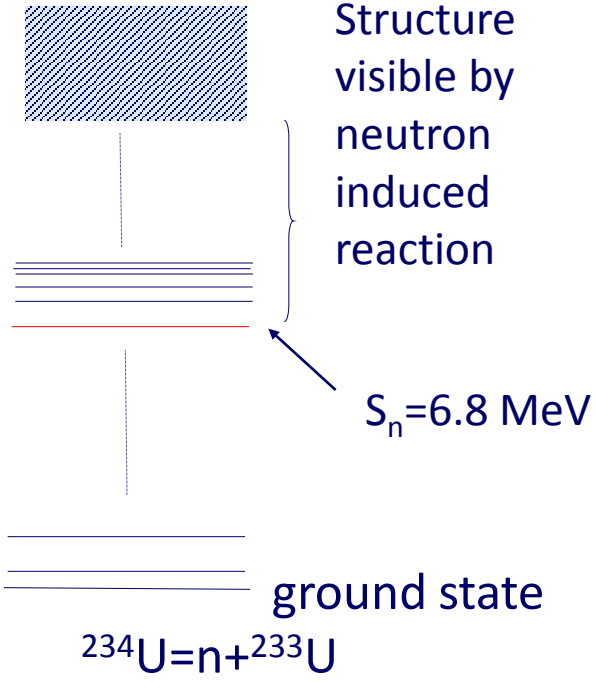
- Fission and fusion energies
- Material analysis
- Medical application

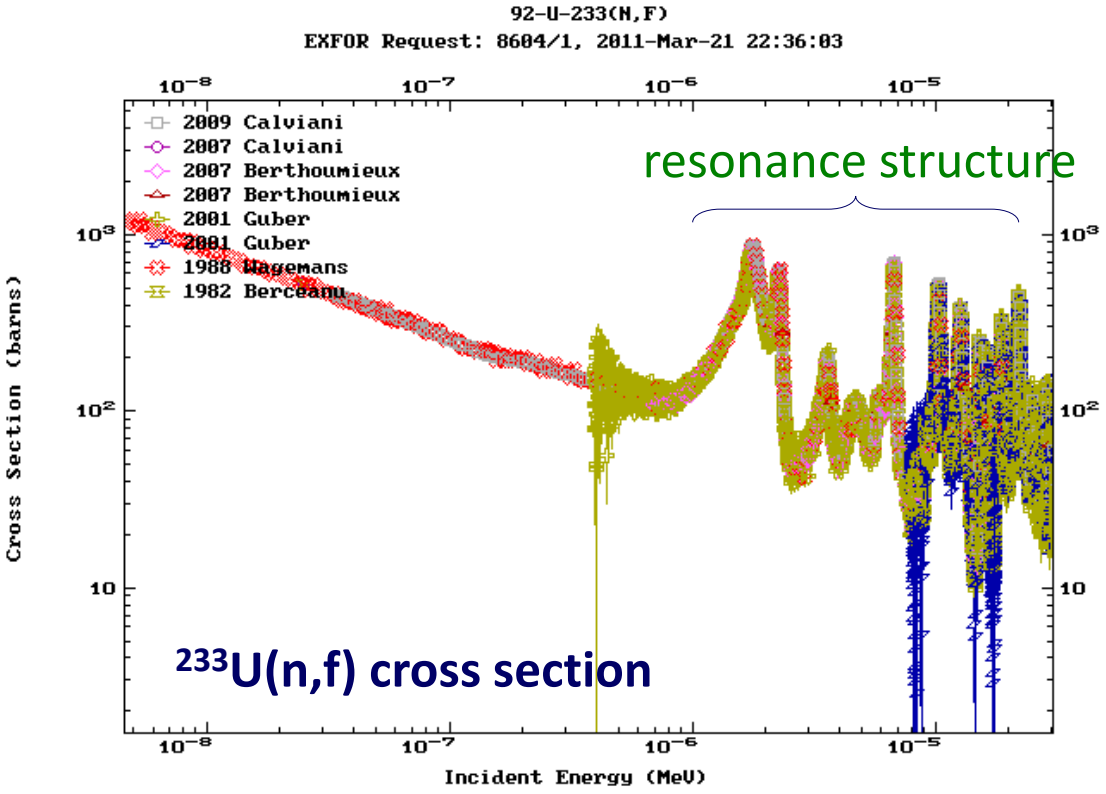
etc.

Experimental Database

Fission cross section in resonance region

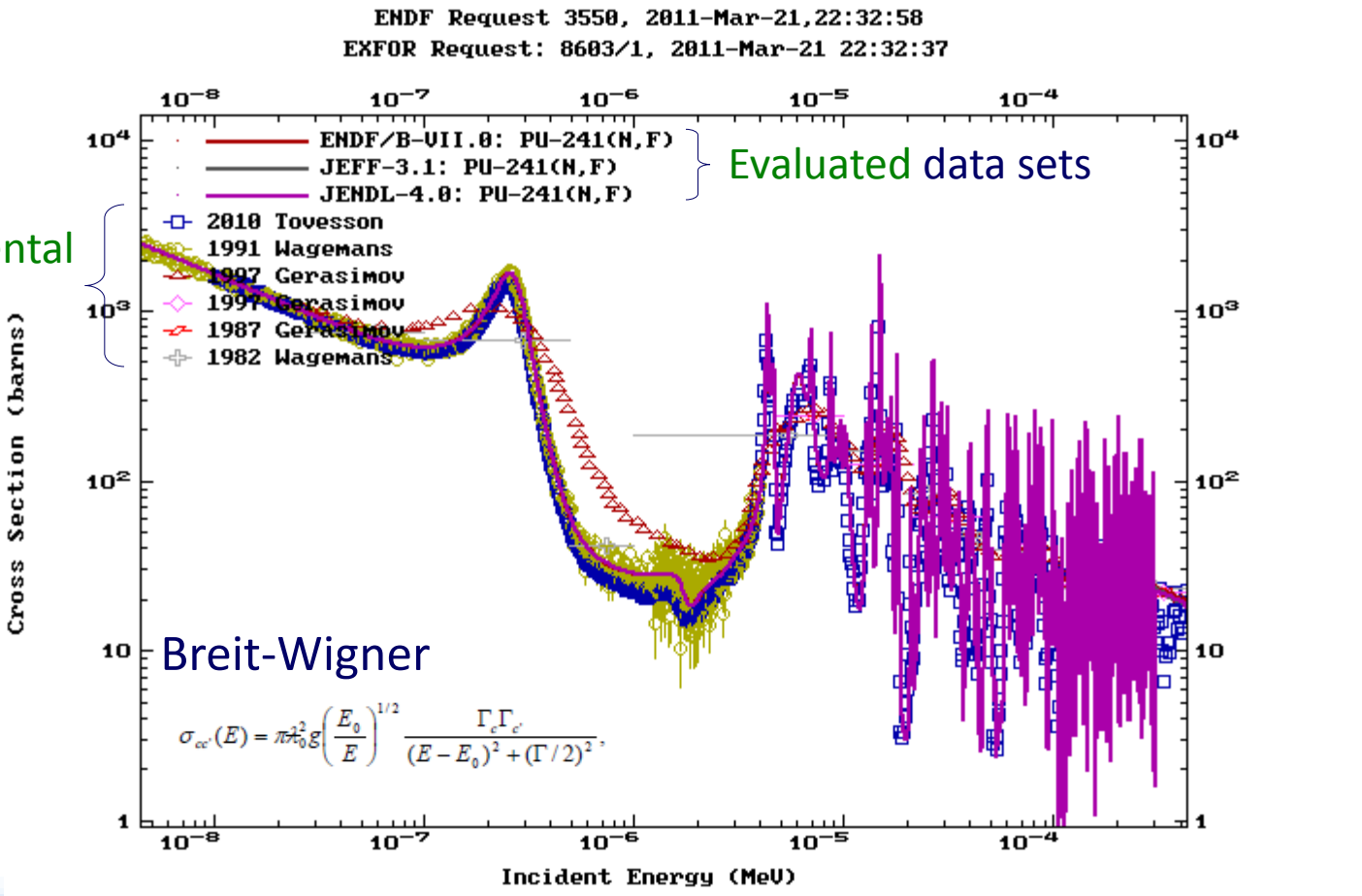
Important for application, theory is not very powerful,
but a lot of experimental data points are available.





Evaluated Database

Evaluated data derived from **experimental data** are used as an input for applications (Breit-Wigner, R-matrix).

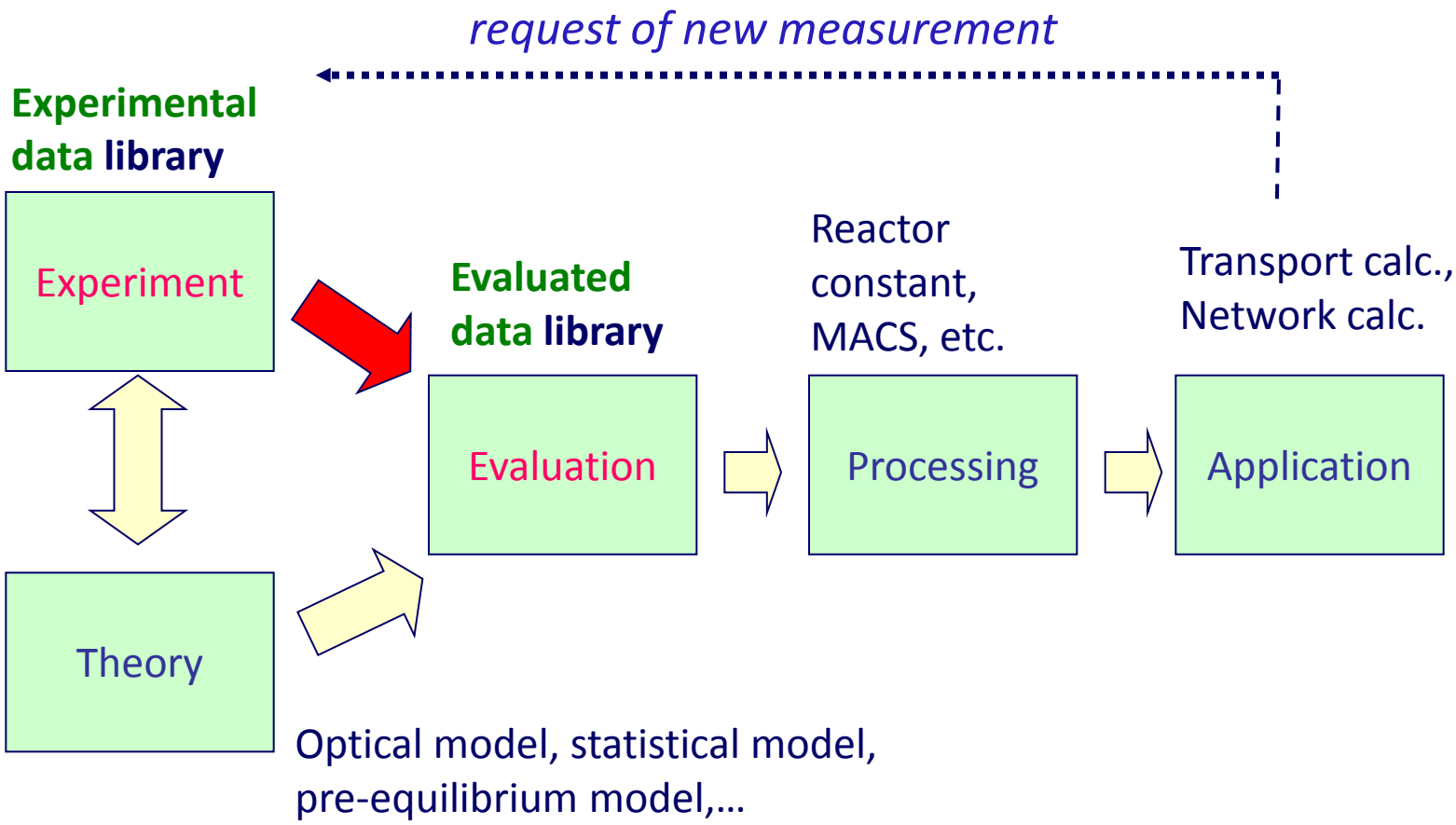


Major Evaluated Nuclear Reaction Database

Library	Released	Countries	Nuclides
JENDL-4.0	2010	Japan	406
CENDL-3.1	2009	China	240
JEFF-3.1.1	2009	EU	381
ENDF/B-VII	2006	US	393
BROND-2.2	1992	Russia	121

(for neutron induced reaction up to 20 MeV)

From Microscopic Experiment to Application



Requirement on Nuclear Database

T. Fukahori (JAEA), July 2011:

- **Reliability**

  Agreement with experimental data

- **Uniqueness**

  One data set for one reaction/quantity (for evaluated database)

- **Completeness**

  All necessary reaction/quantity must be available.

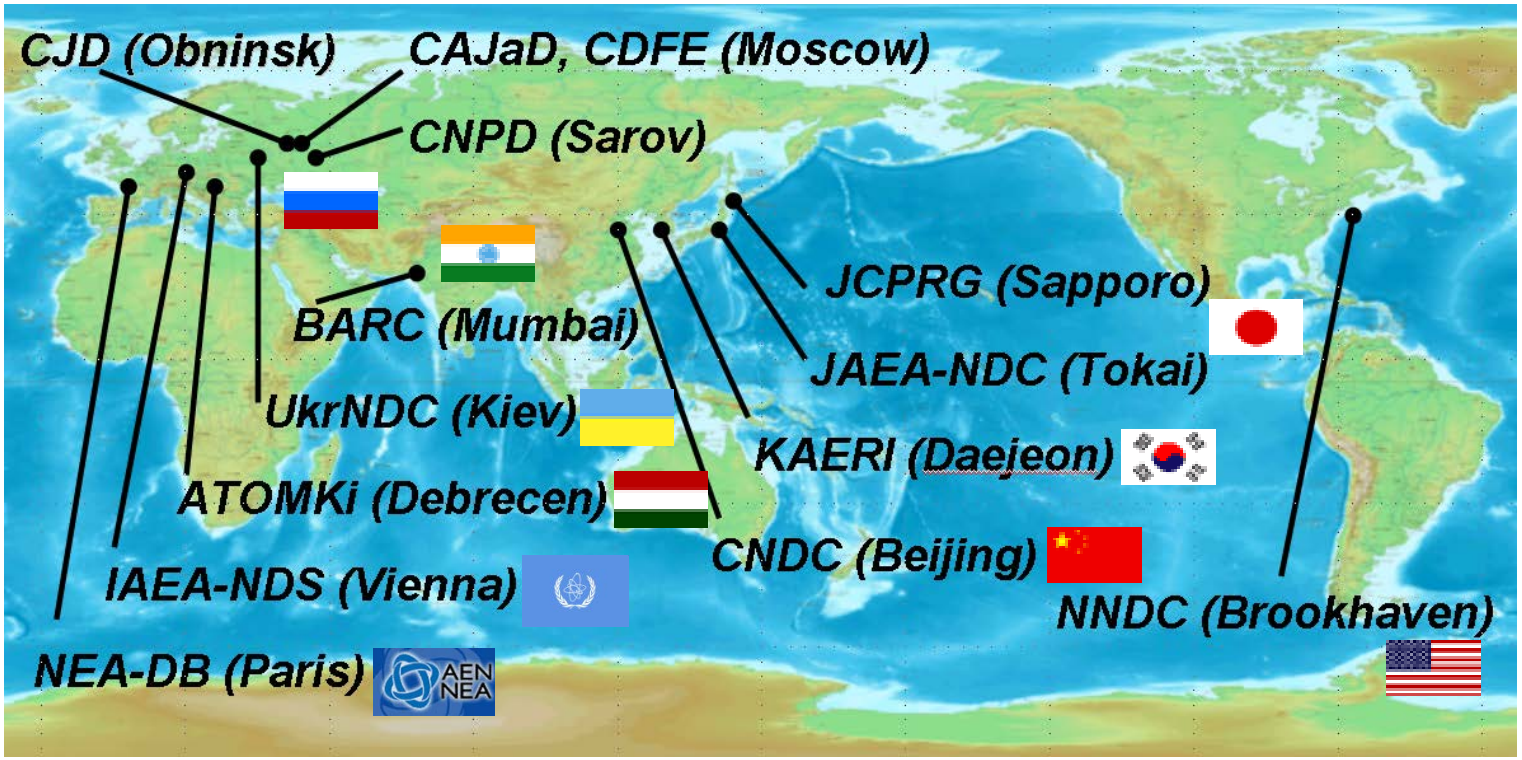
- **Convenience**

  Easy access by various tool

→ Data centre's specific task

Nuclear Reaction Data Centres (NRDC)

EXFOR is a database from international collaboration.



14 centres from 8 countries and 2 international organisations
(China, Hungary, India, Japan, Korea, Russia, Ukraine, USA, NEA, IAEA)
Coordinated by IAEA Nuclear Data Section

NRDC - Brief History

History

1966

- 1st meeting of Four Centres (Brookhaven, Saclay, Obninsk, Vienna)

1969

- EXFOR adopted as official exchange format.

1974

- 1st meeting of Charged-Particle and Photonuclear Data

1979

- 1st meeting of Nuclear Reaction Data Centres

IAEA Headquarters
in Grand Hotel (until **1979**)
(from IAEA Imagebank)

Vicki McLane - 1940-2011

Vicki earned a B.A. in Physics from Adelphi University in 1961. She **joined BNL in 1962** [4 years before the 1st NRDC meeting] as a physics associate in a group that would eventually become the National Nuclear Data Center. Vicki oversaw the compilation and international collaboration activities of neutron reaction data.

Vicki witnessed the thawing of the relations between the USA and the former Soviet Union as the two world super powers started to exchange nuclear physics data. As a matter of fact, Vicki was **one of the early Americans to visit Soviet nuclear physics labs**.

Vicki was very active at the International Atomic Energy Agency (IAEA), focusing on the exchange of nuclear data. She was **an expert in the EXFOR format**, a set of common rules and procedures widely used to store the results of costly nuclear physics experiments performed worldwide.

(from Mike Hermann)

Vicki McLane - 1940-2011 (cont)

Vicki in tee ceremony (2005, Sapporo)

Nuclear Data Center Network
Past, Present, Future

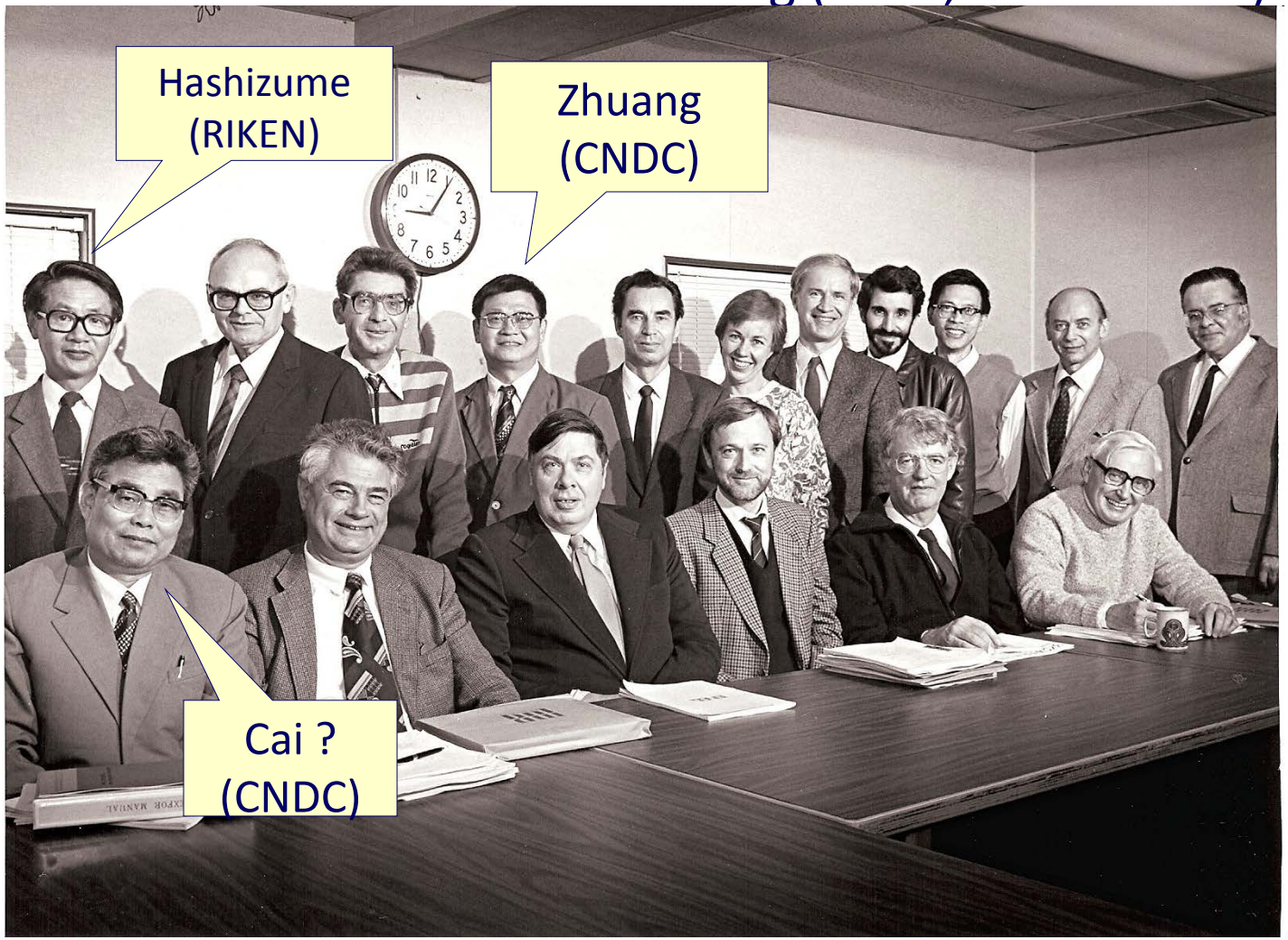
Victoria McLane

National Nuclear Data Center
Brookhaven National Laboratory
and
Hokkaido University

Vicki's last presentation on EXFOR (2005, Sapporo)

NRDC Meeting

Annual NRDC Meeting (1987, Brookhaven)



Courtesy
of V.McLane

NRDC Meeting (cont)

(After?) Annual NRDC Meeting (1987, Brookhaven)

Courtesy
of V.McLane

NRDC Meeting (cont)

Annual NRDC Meeting (2011, Vienna)

Many Asian participants!

Asian Centres

China (1987-)

- EXFOR compilation since Huangshan（黄山）Mountains (1985)
- New generation (Dr. Chen Guochang et al.) is growing.

Japan (1975-)

- Compilation for NRDF and EXFOR database
- New young professor (Prof. M. Aikawa) joined.

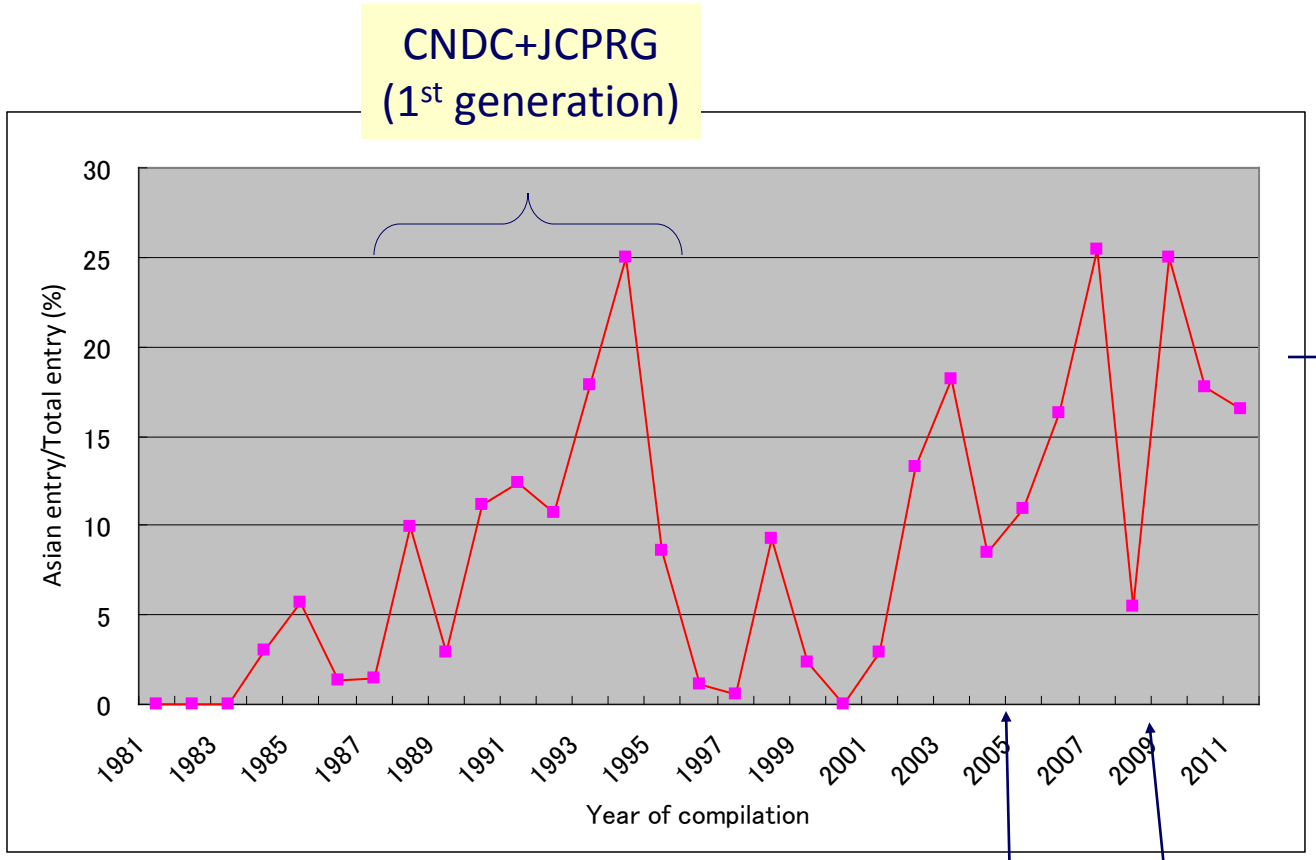
India (2008-)

- Biannual Indian EXFOR workshop (since 2006)
- Dr. Ganesan successfully stabilized it as a *national event*!

Korea (2000-)

- KAERI (Mr Young Sung-Chul) started compilation since 2009..
- Collaboration in ND2010 Conf. Proceedings data

Contribution of Asian Centres to EXFOR Library



Compilation of Asian Work in ND2010 Conf.Proc.

ND2010

International Conference on Nuclear Data for Science & Technology

ND2010 Conf. Proc. is now ready for EXFOR compilation.

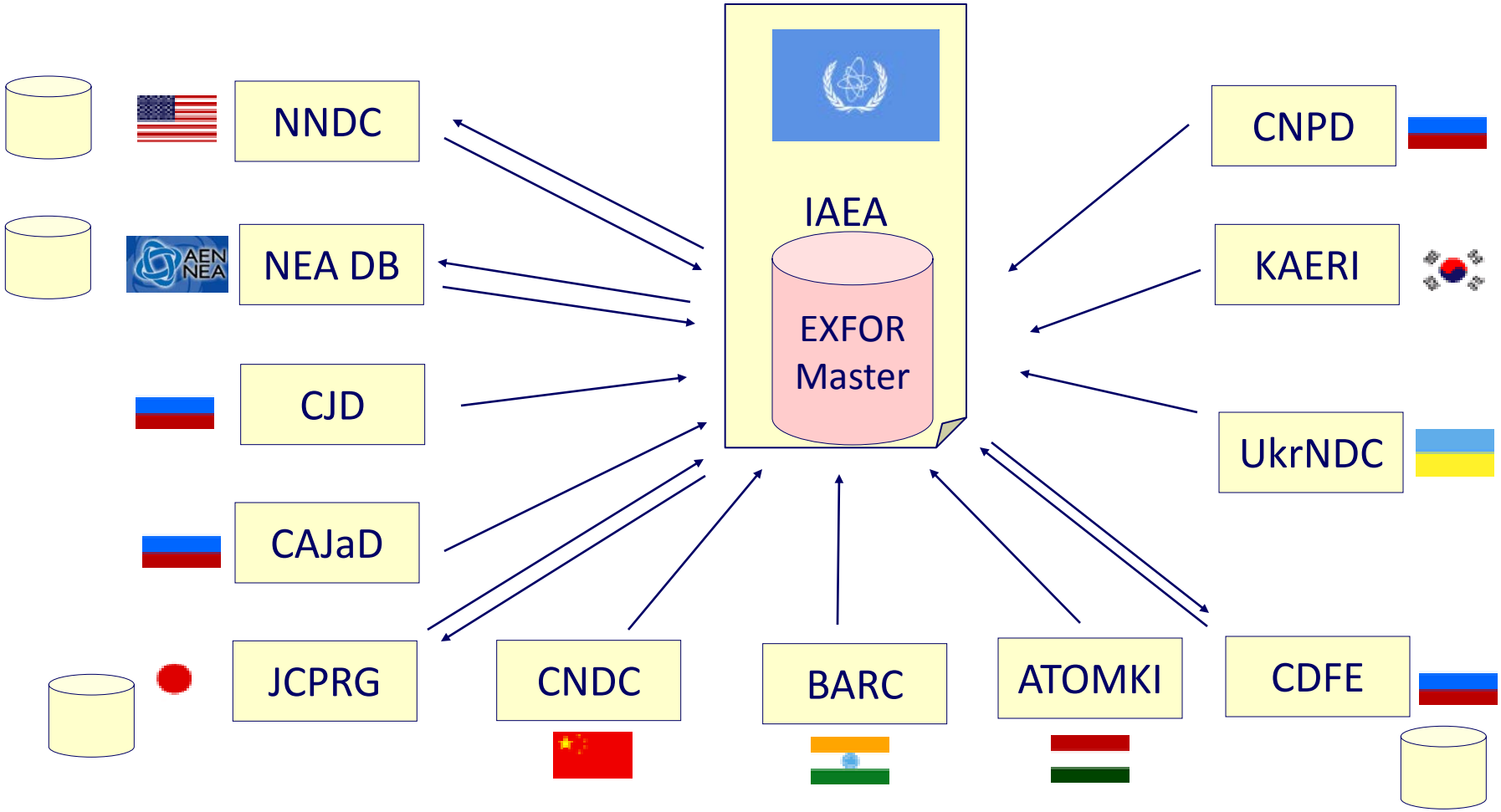
KAERI/NDEL offered various assistance for communication with authors.

Domestic EXFOR Coordination

Indian Centre (NDPCI) stabilizes biannual domestic EXFOR Workshop. It makes nuclear data centre activity more familiar to researchers in nuclear sciences and applications.

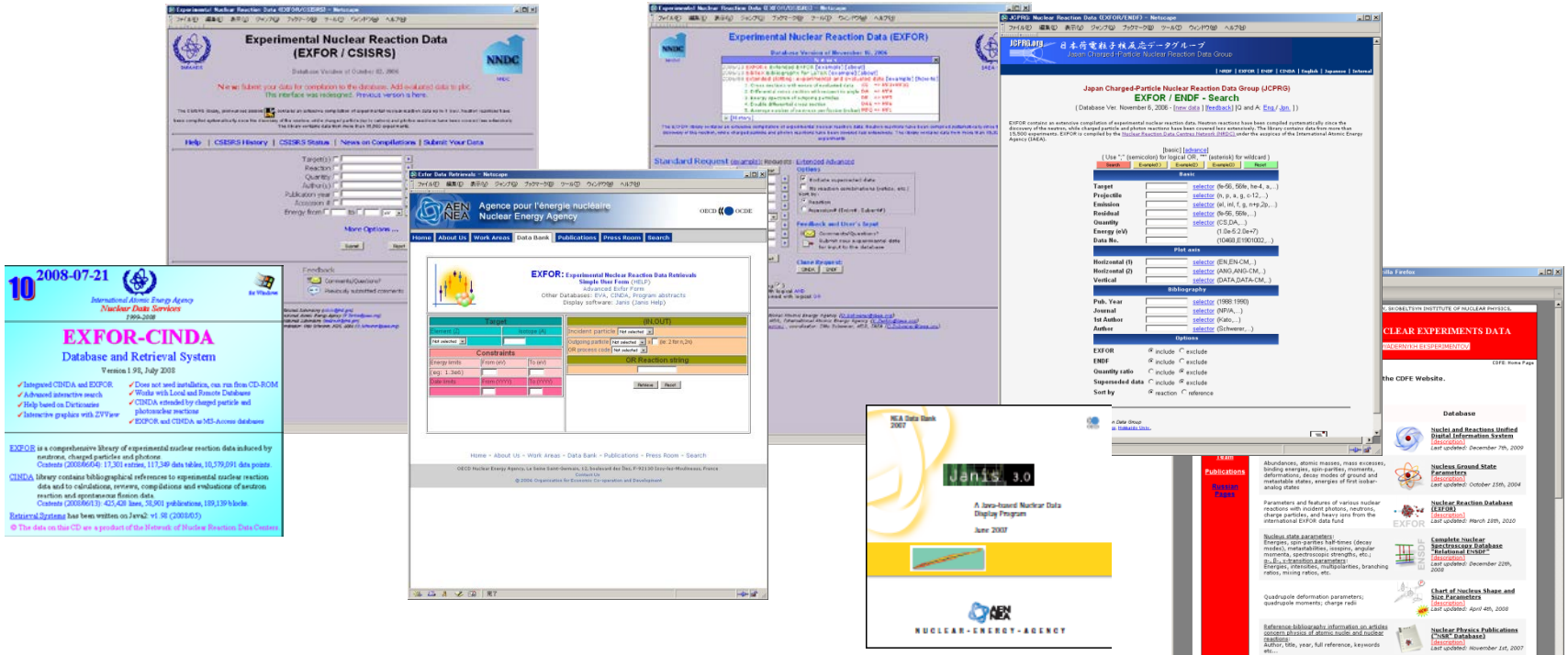
Data Exchange in NRDC

The current exchange structure:



5 centres receive exchanged data and include into their own DB.

EXFOR from Various Centres / Medias



- Centres may use their own database system.

  Example: CSISRS, SIGMA (NNDC), JANIS (NEA-DB), EXFOR (IAEA-NDS)

- However, all centres (should) use the latest EXFOR source files.

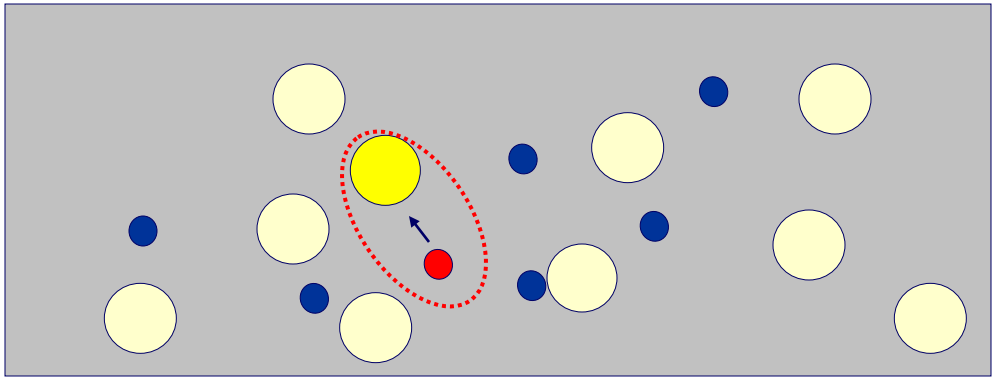
  (IAEA-NDS maintains "**EXFOR Master File**" 2005~)

EXFOR

- EXFOR is a general purpose experimental data library.

  (c.f. ENDF – evaluated nuclear data libraries – are designed for fission and fusion energy systems. En<20 MeV)

- Data describing a microscopic nuclear reaction are considered (c.f. “per incident particle” “per reaction”).



Quantities in EXFOR

- Cross section
- Differential cross section (angular, energy, double, triple, …)
- Resonance parameter
- Fission quantity (fission yield, fission neutron multiplicity, …)
- Polarization quantity (analyzing power, …)
- Thick target yield

for projectile mass ≤ 12 and incident energy ≤ 1 GeV

EXFOR Modern Application

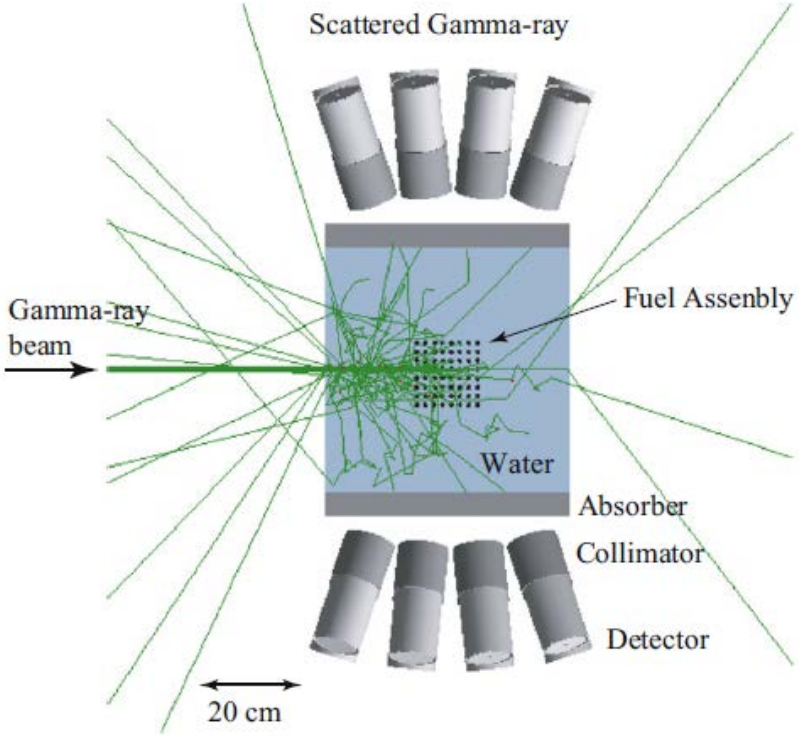
Modern application which I am recently involved

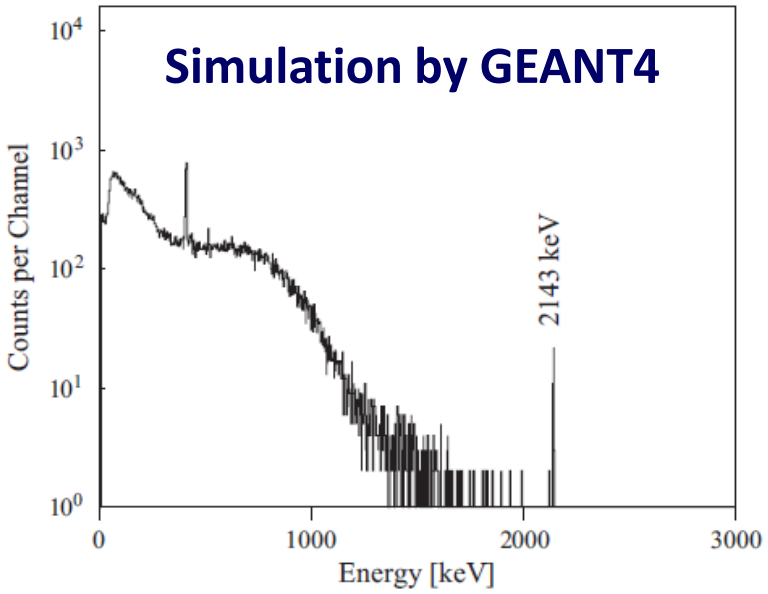
(Theory doesn't work!)

- Neutron source reaction (Fusion)
- Nuclear resonance fluorescence (Safeguards)
- Super-heavy elements production
- Ion beam analysis (Material)
- On-line PET dose monitoring (Medicine)
- etc.

Nuclear Resonance Fluorescence

Non-destructive assay method for actinide (^{239}Pu etc.) in spent nuclear fuel assembly by photon-scattering

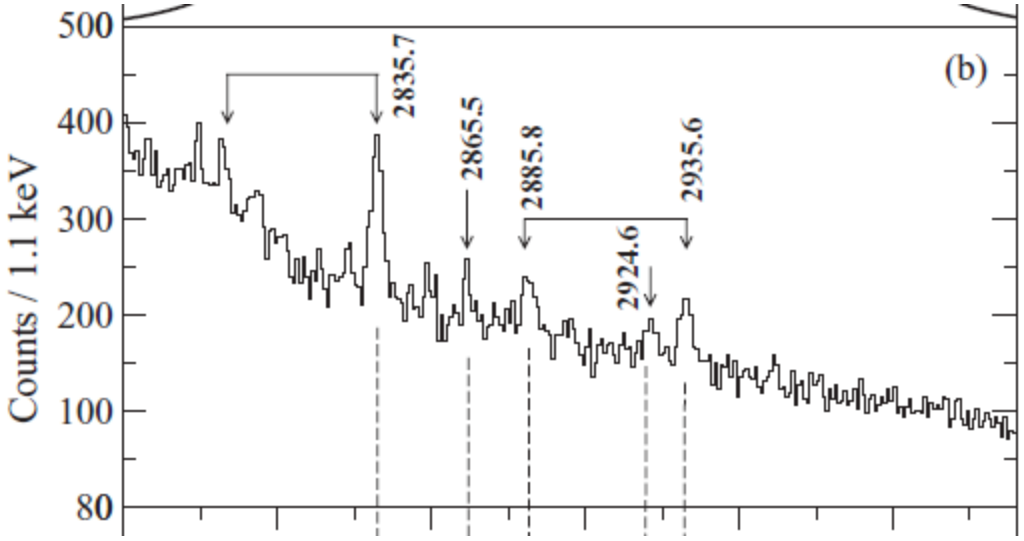


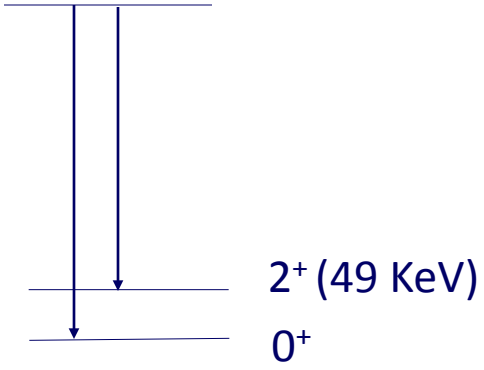


T. Hayakawa et al., Nucl.Instrum.Meth.A621(2010)695

Nuclear Resonance Fluorescence (NRF)

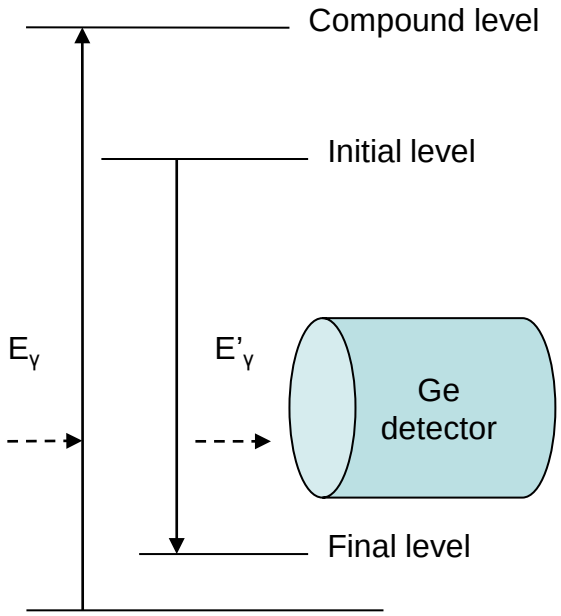
NRF experiment ^{232}Th at TUNL (EXFOR L0159)





A.S. Adekola et al., Phys.Rev.C83(2011)034615

Nuclear Resonance Fluorescence (cont)



To quantify the amount of nuclides, we have to know

- Useful resonance level
- Cross section (area)

Nuclear databases are poor for the information.

Nuclear Resonance Fluorescence (cont)

Our knowledge is poor even for ^{235}U levels!
Accumulation of more experimental data are required.

Experimental data (MIT)

Isotope	Transition (keV)	Statistical significance	Cross section (eV·b)
^{235}U	1656.23(80)	5.8	4.1(13)
	1687.26(33)†	10.2	6.1(11)
	1733.60(22)†	56.4	29.8(39)
	1769.16(28)‡	9.3	4.4(10)
	1815.31(22)‡	19.9	9.7(17)
	1827.54(23)	13.3	6.7(12)
	1862.31(20)	20.1	9.6(17)
	2003.32(25)	14.5	9.7(17)
	2006.19(31)	7.2	4.7(16)

W.Bertozzi et al., Phys.Rev.C78(2010)041601

?

Evaluated data (ENSDF)

1606.26 25	(35/2-)
1635.51 16	(25/2-)
1647.01 13	(23/2-)
1802.8 3	(37/2-)
1987.0 4	(39/2-)
2202.1 4	(41/2-)

E. Browne, Nucl. Data Sheets 98(2003)665
(adopted levels)

EXFOR Compilation

Experiment

Publication

Articles

Journal scan

List of articles

Allocation to data centres

Compilation

EXFOR (prelim.)

Review, correction

EXFOR

Database

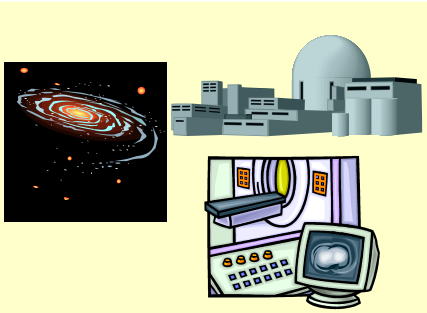
Processing and output

Internet
CD-ROM, DVD

Users

Application

Planning of new experiment



EXFOR Formats

- Each EXFOR entry is stored in an ASCII file.

- Each line of EXFOR entry has 80 columns.
  (67th-80th columns: Line sequential number)

- Each EXFOR subentry is divided into
  1) BIB section: Description of the experiment
  2) COMMON section: numerical data (constants of the data set)
  3) DATA section: numerical data

Example of EXFOR File

BIB section

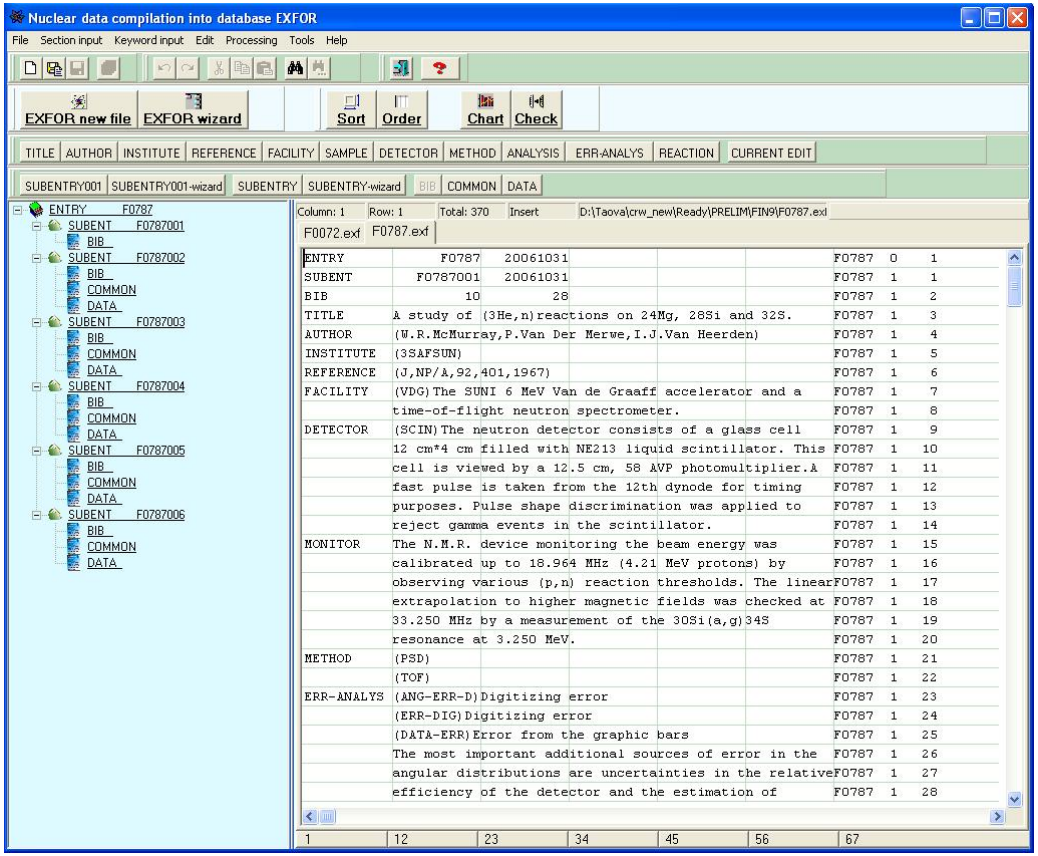
DATA section

```
         11        22        33        44        55        66          80
---------+---------+---------+---------+---------+---------+----------+---------+
SUBENT        33023003   20110104                                33023003     1
BIB                4          4                                  33023003     2
REACTION      (91-PA-233(N,F),,SIG)                               33023003     3
MONITOR       ((MONIT)92-U-235(N,F),,SIG) ENDF-B/VII              33023003     4
MONIT-REF     (,,3,ENDF-B/VII.0,,2006)                            33023003     5
STATUS        (DEP,33023002) 233Pa(n,f)/235U(n,f) data @ given E*  33023003     6
ENDBIB             4                                              33023003     7
NOCOMMON           0          0                                   33023003     8
DATA               5          6                                   33023003     9
EN            DATA       ERR-S      EN-NRM     MONIT              33023003    10
MEV           B          B          MEV        B                  33023003    11
 11.83         0.8832     0.076      10.50      1.703              33023003    12
 12.83         0.8754     0.076      11.50      1.799              33023003    13
 13.84         0.8986     0.066      12.51      1.988              33023003    14
 14.84         0.9444     0.071      13.51      2.091              33023003    15
 15.85         1.1347     0.077      14.52      2.151              33023003    16
 16.85         1.4780     0.1        15.52      2.122              33023003    17
ENDDATA            8                                              33023003    18
ENDSUBENT         17                                              3302300399999
```

We do not want edit it manually...

Collaboration in Compilation Tool

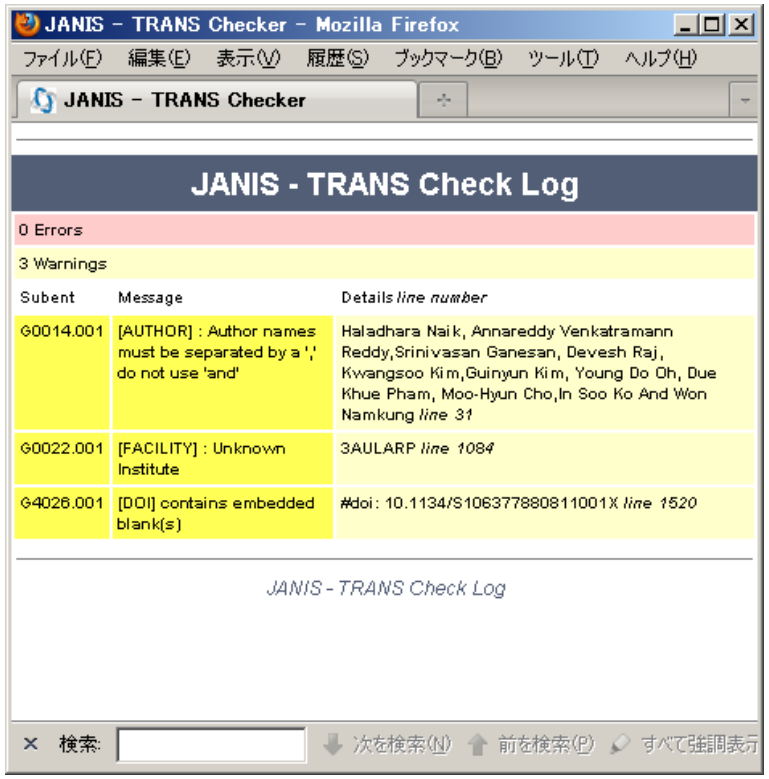
ExforEdit (to edit ascii files in the EXFOR Formats on Windows)



Developed by **Centre of Nuclear Physics Data** (Sarov)

Collaboration in Compilation Tool (cont)

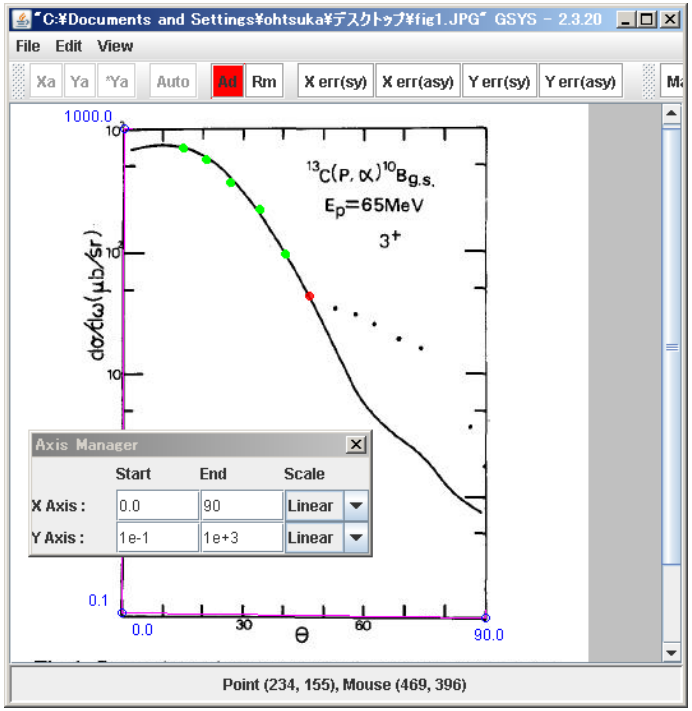
Janis TRANS Checker (to check EXFOR files on Windows, Linux, Mac)



Developed by **NEA Data Bank** (Paris)

Collaboration in Compilation Tool (cont)

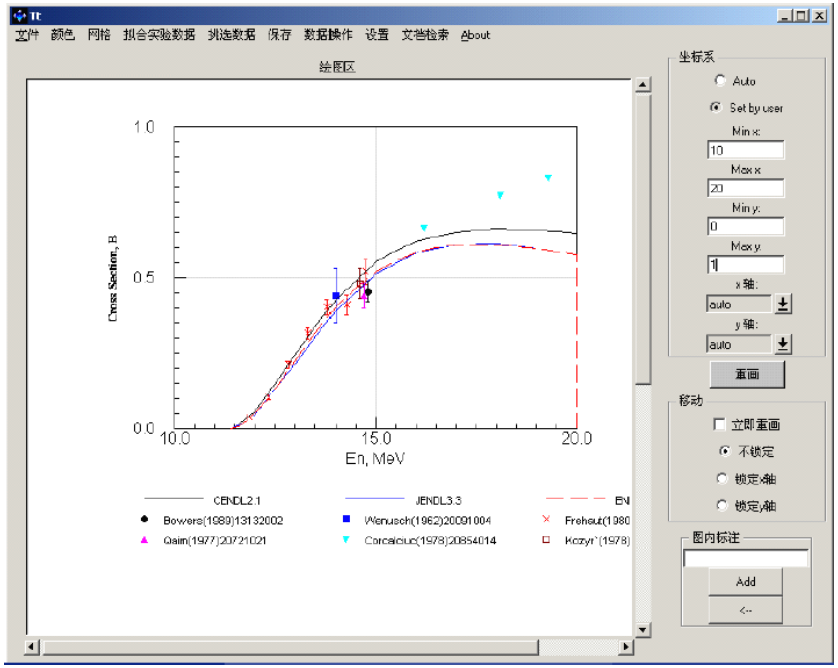
GSYS (to digitize numerical data from images on Windows, Linux, Mac)

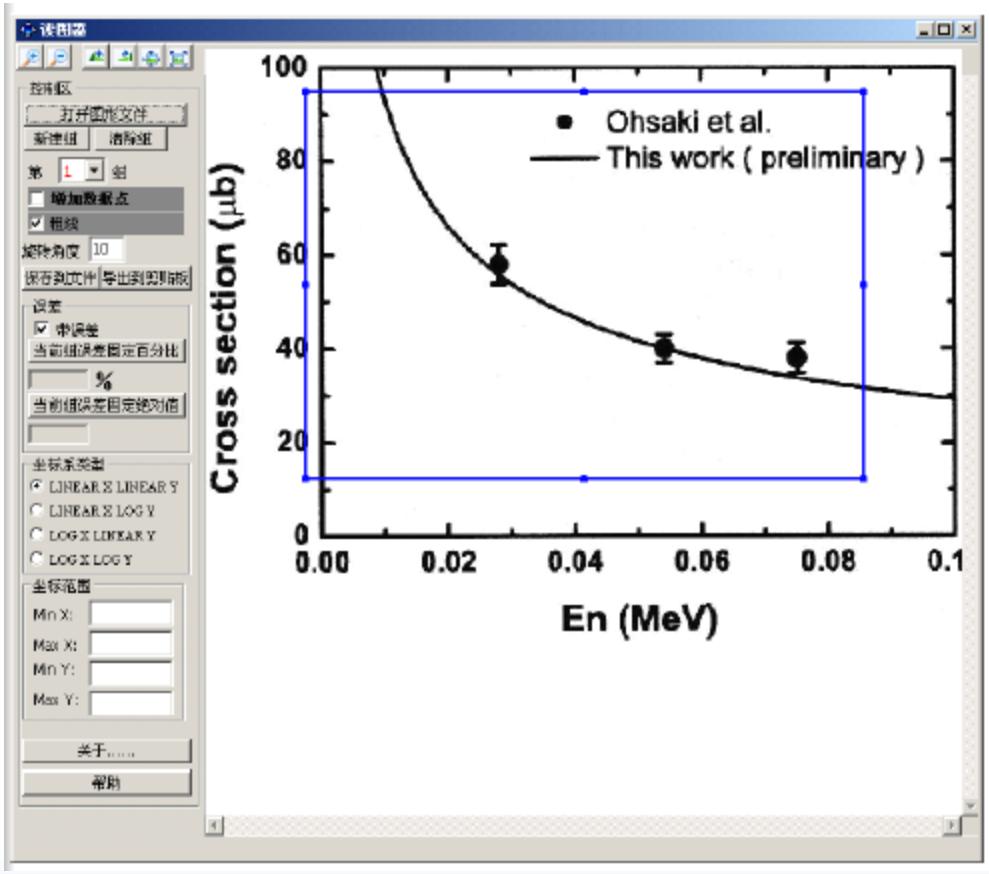


Developed by **Hokkaido Univ.** (JCPRG)

Collaboration in Compilation Tool (cont)

Do you have local tools available for other centres?





Example: Chinese utilities
(Chen-san's presentation
in Vienna)

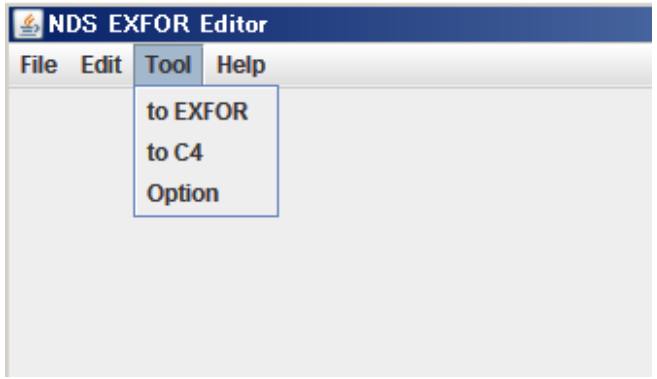
EXFOR Editor – Next generation

- **Sarov Editor** makes EXFOR compilation easier. However it still requires a lot of EXFOR Format rules (e.g., 11 columns rule!). Works only on Windows.

- **Japanese Editor** (HENDEL) solves these problems. However, it is specialized for the scope of Japanese Centre compilation.

- I want to have a new **java** based (i.e., works on Windows, Linux, etc.) editor.

My first java programming (last Saturday)→



EXFOR Formats - Future

Major problems in the current EXFOR Formats

- Cannot describe complicated reaction
  (coincident in fission, multi-step reaction, c.m.s. of a cluster)

- Users cannot extract EXFOR information easily
  (Evaluators want to extract necessary information *systematically*.)

Does XML help EXFOR users ??

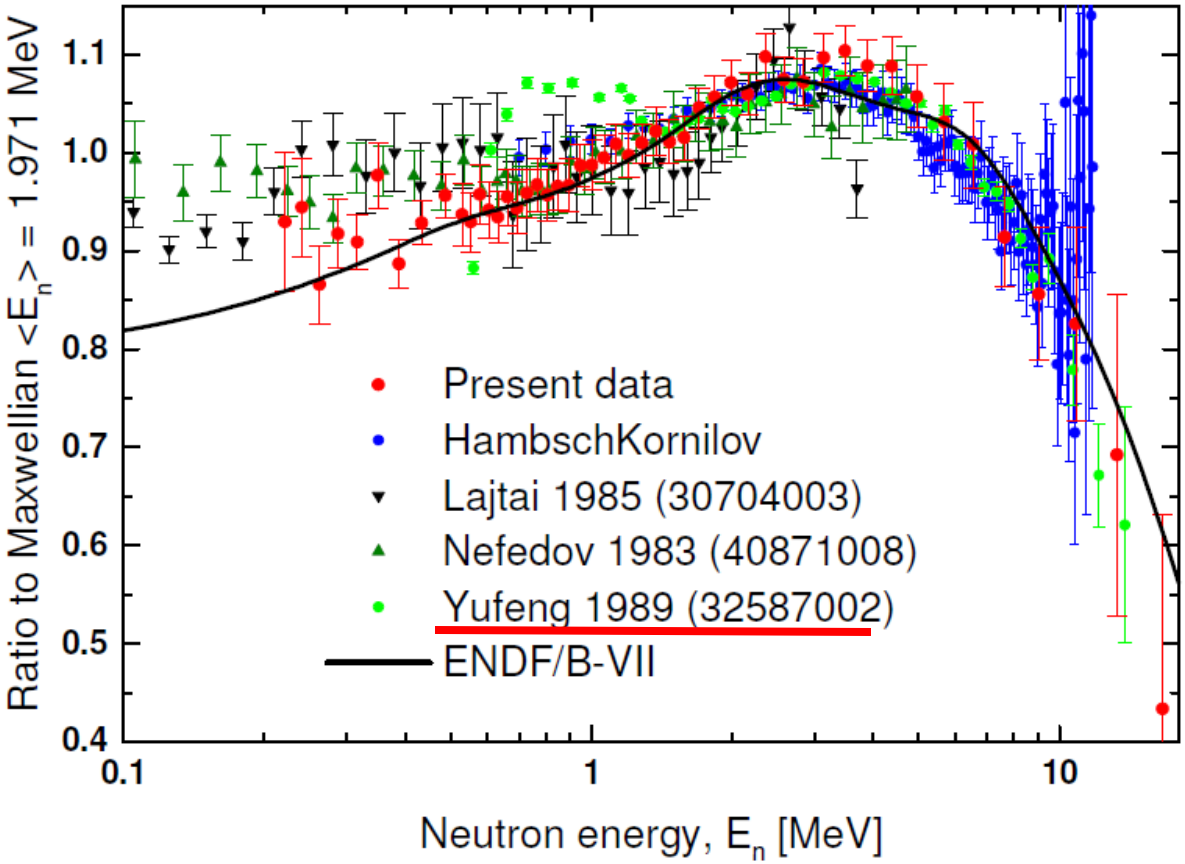
EXFOR in XML – Designed by P. Talou (LANL), July 2011

ν_p of $^{238}Pu(n_{th},f)$= 1.008 ±0.011
measured relative to $^{239}Pu(n_{th},f)$= 2.884 ±0.007

```
<exfor entry=10125 subentry=003>
 <target>94238</target>
 <reaction>(n,f)</reaction>
 <dataType>nup</dataType>
  <monitor>
   <reaction>(94-PU-239(N,F),PR,NU,,MXW)</reaction>
    <datum type="xydy" xUnit="MeV" yUnit="no-dim" dyUnit="no-
   dim">2.53e-8 2.884 0.007</datum>
  </monitor>
  <data number=1 type="xydy" xUnit="MeV" yUnit="no-dim" dyUnit="no-
   dim">
   <datum>2.53e-8 1.008 0.011</datum>
  </data>
</exfor>
```

Asian Name in EXFOR

"**Yufeng**" is a famous person in ^{235}U+n PFNS study



A.S.Vorobyev et al. (Oct. 2010, Vienna)

Asian Name in EXFOR

Wrong Citation

An example of citation from Chin.J.Nucl.Phys. (EXFOR 32587)

6. B.I. Starostov et al., in *Proceeding of 6-th Conf. for Neutron Phys., Kiev. 1983*, Nejtronnaja Fizika, 1984. T.2. C.285, 290, 294, EXFOR 40871, 40872, 40873.
7. W. Yufeng et al., Chin. J. Nucl. Phys. **11**, 47 (1989). EXF32587.
8. P. Staples et al., Nucl. Phys. A **591**, 41 (1995)

N. Kornilov et al., ND2007 Conf.Proc.

But “Yufeng” does not look like Chinese name…

Wrong Citation (cont)

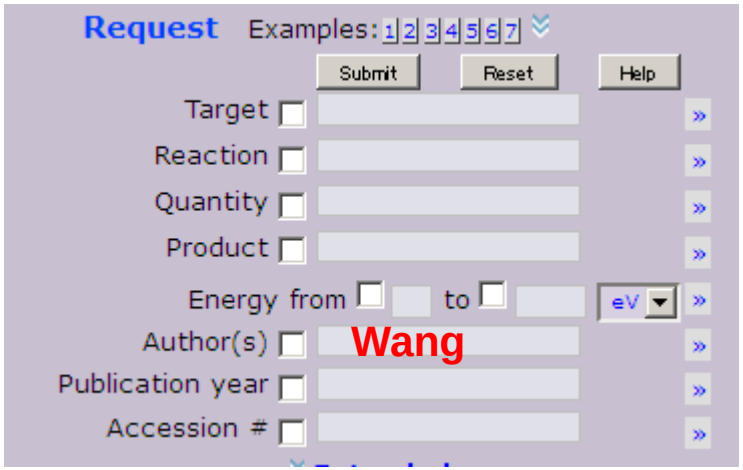
```
ENTRY            32587   20100328
SUBENT        32587001   20100328
BIB                 13         33
TITLE       Experimental study of                    um
            of U-235 fission induced                 thermal neutrons.
INSTITUTE   (3CPRAEP)REFERENCE (J,CNP,11,(4),47,198911)
AUTHOR      (Wang Yufeng, Bai Xixiang,Li Anli,Wang Xiazhong,
             Li Jingwen,Meng Jiangchen,Bao Zhongyu)
FACILITY    (REAC,3CPRAEP)
…
SUBENT        32587002   20101028
BIB                  2          3
REACTION    (92-U-235(N,F),PR,NU/DE,,MXW/REL)
HISTORY     (20101028A) REACTION code corrected:
             SF6-SF7: DE,N => NU/DE,,
ENDBIB               3
NOCOMMON             0          0
DATA                 3         44
E           DATA        DATA-ERR
MEV         NO-DIM      NO-DIM
       0.56  2.025E+06    1.6E+04
       0.61  2.311E+06    1.6E+04
       0.66  2.398E+06    1.4E+04
```

Wang Yufeng

EXFOR users wrongly recognized his (her?) family name as "**Yufeng**"…

Should we code it as **Y.F.Wang** or **Y.Wang** in EXFOR?

EXFOR Search by Asian Name



In IAEA system, Wang's work should be searched by

" ***Wang*** ".

It matches

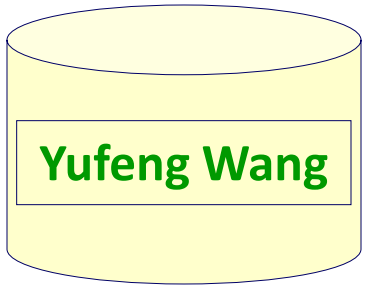
Yufeng <u>Wang,</u>

<u>Wang</u> Yufeng,

Y.F.<u>Wang</u>

?

NDS system assumes it is coded as "Y.Wang", "Y.F.Wang" etc.



EXFOR Database

Asian name in EXFOR – Edit author's name?

Should compilers make initials:

Wang Yufeng → **Y.F.Wang**??

This is difficult for western compilers.

Isomeric yield ratios for the formation of ^{44m,g}Sc in the ^{45}Sc(γ ^{nat}Fe(γ,xn5p) and ^{nat}Cu(γ,xn8p) reactions with 2.5 GeV brems

Nguyen Van Do[a], Pham Duc Khue[a], Kim Tien Thanh[a], Le Truong Son[b, 1], Md. Shakilur Rahman[c], Kyung-Sook Kim[c], Manwoo Lee[c], Guinyun Kim[c], , , Youngdo Oh[d], Hee-Seock Lee[d], Moo-Hyun Cho[d], In Soo Ko[d] and Won Namkung[d]

```
SUBENT        M0758001   20090323   20090402   20090324        M047
BIB                 13         48
TITLE       Isomeric yield ratios for the formation of 44m,gSc in
             the 45Sc(g,n),  nat-Ti(G,xnp),  nat-Fe(g,xn5p)   and
             nat-Cu(g,xn8p) reactions with 2.5 GeV Bremsstrahlung.
AUTHOR      (N.VAN DO, P.D.KHUE,K.T.THANH,L.T.SON,M.D.S.RAHMAN,
             K.-S.KIM,M.LEE,G.KIM,Y.OH,H.-S.LEE,M.-H.CHO,
             I.S.KO,W.NAMKUNG)
INSTITUTE   (3VN VN,3KORKNU,3KORPUE)
```

The European compiler could not know **Nguyen** is his family name ☹

Summary

- EXFOR has successfully publicized experimental work published in regional journals to researchers in the world.
- Current Asian names (e.g., China, Vietnam, Korea) coded by EXFOR "AUTHOR" sometimes not used properly by EXFOR users and systems.
- I do not have a good solution for it. The Asian Centre group could be at a good position to make a proposal to NRDC.

Summary

- Experimental and evaluated nuclear database are essential resource to solve nuclear network system.
- Development of nuclear database is a unique responsibility of researchers engaged to nuclear data centres.
- EXFOR database contributes to dissemination of experimental works published in regiona publication and language to the world.
- Thank you very much for inviting me to the “2nd Asian Nuclear Reaction Database Development Workshop”.
- I wish the Asian collaboration will be stabilized as a unique event organized by Asian data centres with “database” as a keyword.