International Atomic Energy Agency

The 6th DAE-BRNS Theme Meeting on

EXFOR Compilation of Nuclear Data

Department of Physics, Bangalore University, Bangalore, India

20–24 January 2015

Goal of the Workshop

Naohiko OTSUKA

Nuclear Data Section

Department of Nuclear Sciences and Applications

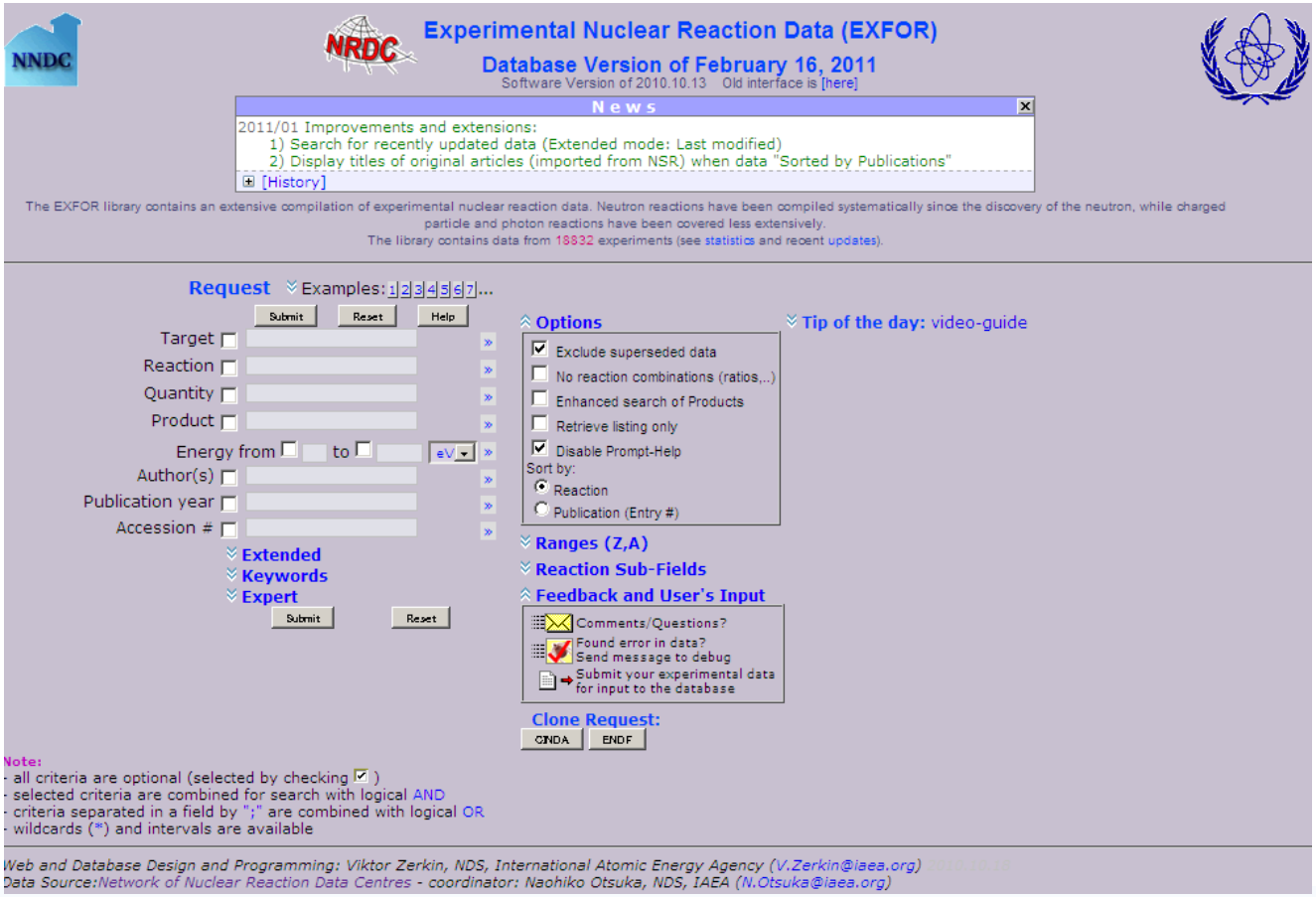
Outline of Workshop

- Nuclear Database (General)
- EXFOR/ENDF Search
- EXFOR Compilation I – Bibliography, exp. condition.
- EXFOR Compilation II – Experimental parameters
- EXFOR Compilation III – Data tables
- Digitization tool
- Checking tools

You have to submit your EXFOR entry after clerance by the end of this workshop!

After this Workshop …

All your EXFOR entries will be stored in the IAEA EXFOR database.
You are responsible to distribute Indian data correctly.



Goal of this Workshop

- To understand the idea of “nuclear database”.
- To be able to search and process EXFOR data.
- To be able to prepare EXFOR entries.

The ultimate goal:

Creation of EXFOR entries form your own experiments!

A Successful Workshop Participant – Dr. Chitra Bhatia

PHYSICAL REVIEW C 87, 011601(R) (2013)

^{136}Xe(n,2n)^{135}Xe cross section between 9 and 15 MeV

C. Bhatia,[1,2,*] S. W. Finch,[1,2] M. E. Gooden,[2,3] and W. Tornow[1,2]
[1]*Department of Physics, Duke University, Durham, North Carolina 27708, USA*
[2]*Triangle Universities l*
[3]*Department of Physics, North*
(Received 1

EXFOR 14355
(Jan. 2013)

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SUBENT        14355001   20130125                              14355  1    1
BIB                12         23                              14355  1    2
TITLE      136Xe(n,2n)135Xe cross section between 9 and 15 MeV  14355  1    3
AUTHOR     (C.Bhatia, S.W.Finch, M.E.Gooden, W.Tornow)         14355  1    4
INSTITUTE  (1USADKE,1USATNL,1USANCS)                           14355  1    5
REFERENCE  (J,PR/C,87,011601,2013)                             14355  1    6
FACILITY   (VDGT,1USATNL)                                      14355  1    7
...
STATUS     (TABLE) Table I of Phys.Rev.C87(2013)011601          14355  1   24
HISTORY    (20130125C) Chitra Bhatia                           14355  1   25
```

She compiled data in her 3 PRC articles published in 2012-2013!

TABLE I. Summary of cross-section results. $\Delta\sigma_1$ = statistical uncertainty. $\Delta\sigma_2$ = total uncertainty.

E_n (MeV)	^{136}Xe(n, 2n)^{135}Xe σ (mb)	^{136}Xe(n,2n)^{135}Xe^m $\Delta\sigma_1$	$\Delta\sigma_2$	σ (mb)	$\Delta\sigma_1$	$\Delta\sigma_2$
8.96 ± 0.09	265.09	1.50	12.12	21.71	0.33	0.99
9.46 ± 0.13	558.29	0.94	20.60	198.13	2.10	7.24
9.96 ± 0.13	746.97	1.10	24.90	290.01	3.40	10.48
10.95 ± 0.20	1344.73	1.3	40.01	552.44	3.21	17.64
11.94 ± 0.21	1630.47	3.98	44.50	763.13	2.72	20.26
12.94 ± 0.20	1751.34	3.20	40.95	864.13	2.33	22.04
13.75 ± 0.20	1813.19	2.22	33.11	870.56	1.51	15.05
14.45 ± 0.19	1794.11	2.45	40.02	848.85	1.78	18.70
14.85 ± 0.05	1727.85	2.66	53.15	845.42	1.81	25.58

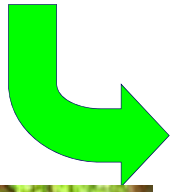
A Successful Workshop Participant – Dr. Megha Bhike

PHYSICAL REVIEW C **89**, 031602(R) (2014)

Neutron-capture cross-section measurements of ^{136}Xe between 0.4 and 14.8 MeV

Megha Bhike and W. Tornow
Department of Physics, Duke University, Durham, North Carolina, 27708, USA
and Triangle Univer
(Rec

EXFOR 14385
(Apr. 2014)




```
SUBENT        14385001   20140404                              14385  1    1
BIB                14         34                              14385  1    2
TITLE      Neutron-capture cross-section measurements of 136Xe  14385  1    3
           between 0.4 and 14.8 MeV                            14385  1    4
AUTHOR     (M.Bhike, W.Tornow)                                 14385  1    5
INSTITUTE  (1USADKE,1USATNL)                                   14385  1    6
REFERENCE  (J,PR/C,89,031602,2014)
FACILITY   (VDGT,1USATNL)
...
STATUS     (TABLE)Table II of of Phy.
HISTORY    (20140404C)compiled by Meg
```

TABLE II. Neutron energy and energy spread, monitor reaction cross-section values used, and ^{136}Xe$(n,\gamma)^{137}$Xe cross-section results obtained in the present work.

Neutron energy $E_n \pm \Delta E_n$ (MeV)	Monitor reactions σ (mb)	^{136}Xe$(n,\gamma)^{137}$Xe σ (mb)
0.37 ± 0.11	170 ± 5.1	0.61 ± 0.08
0.85 ± 0.11	38.93 ± 1.60	0.74 ± 0.08
1.30 ± 0.12	130.23 ± 3.13	1.00 ± 0.12
1.85 ± 0.12	238.71 ± 5.73	0.70 ± 0.07
2.74 ± 0.15	344.40 ± 8.09	0.59 ± 0.08
3.34 ± 0.15	336.66 ± 7.91	0.96 ± 0.22
4.10 ± 0.62	318.20 ± 7.48	1.09 ± 0.11
5.66 ± 0.39	341.90 ± 8.89	0.89 ± 0.09
6.24 ± 0.36	347.62 ± 11.47	0.62 ± 0.09
7.31 ± 0.30	345.04 ± 11.39	0.57 ± 0.16
14.79 ± 0.08	2166.16 ± 23.40	0.73 ± 0.07

She compiled data in her 1 PRC and
1 PLB article published in 2014!
(Also a new PRC article in January ’15!)

No new EXFOR entry from a successful **man** participant in these years… (“successful”=compile data published in his own publication in EXFOR)

International Atomic Energy Agency

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Department of Physics, Bangalore University, Bangalore, India

20–24 January 2015

Introduction to Nuclear Data

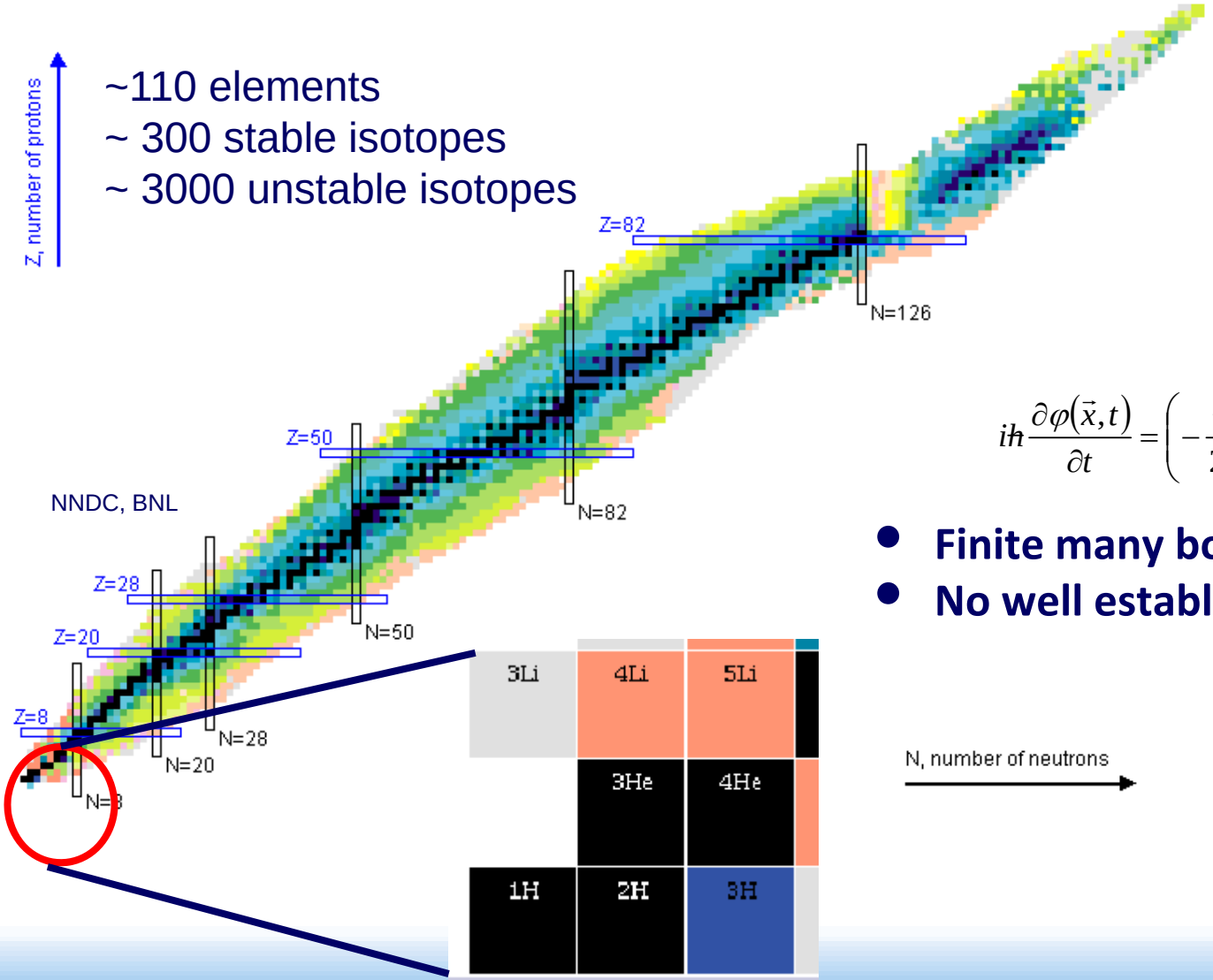
Naohiko OTSUKA

Nuclear Data Section

Department of Nuclear Sciences and Applications

Basic Nuclear Physics

~110 elements
~ 300 stable isotopes
~ 3000 unstable isotopes



$$i\hbar\frac{\partial\varphi(\vec{x},t)}{\partial t}=\left(-\frac{\hbar^2}{2m}\Delta+V(\vec{x})\right)\varphi(\vec{x},t)$$?

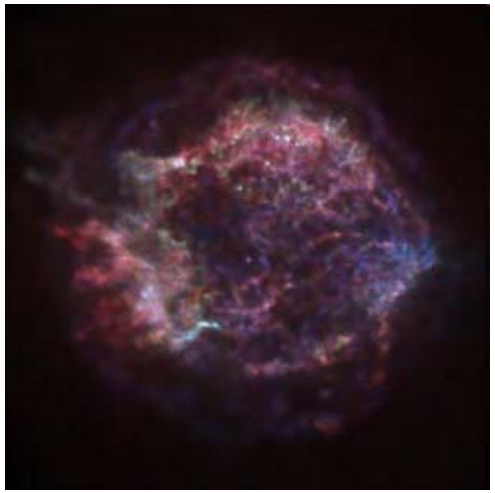
- **Finite many body system**
- **No well established interaction**

Nuclear Reaction Network in Science

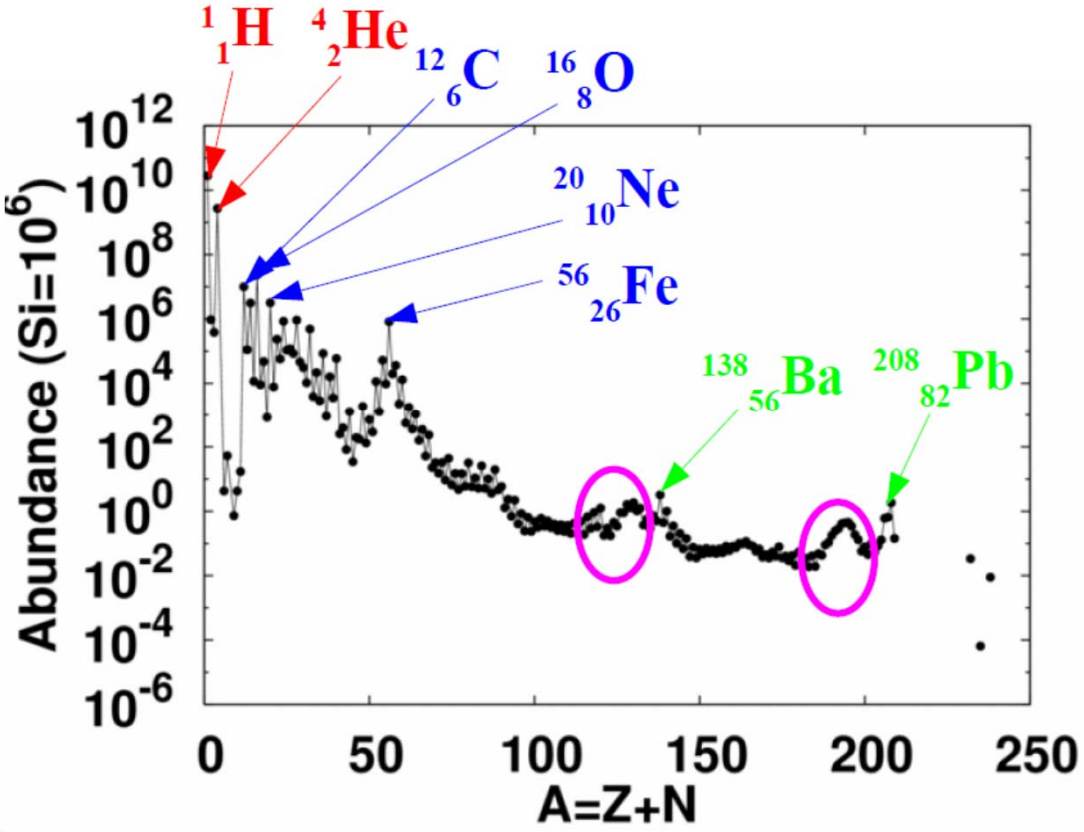
Nucleosynthesis

How do we understand isotopic abundances?

Isotopic abundances in the universe

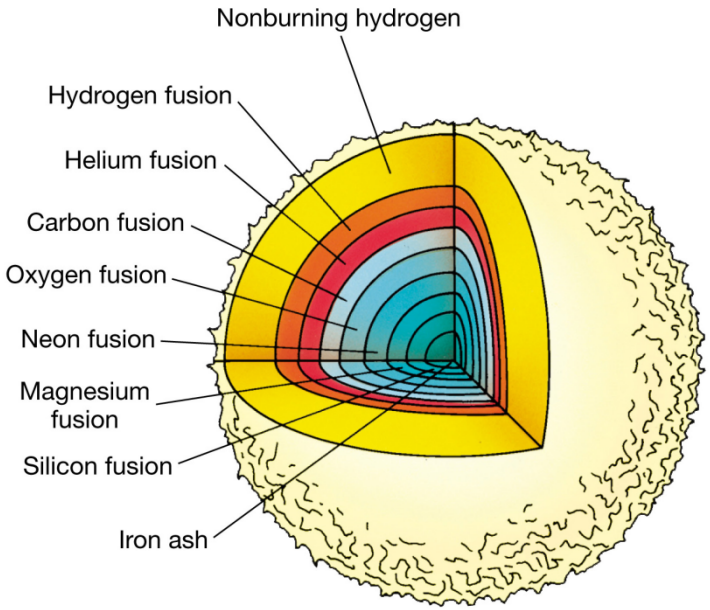


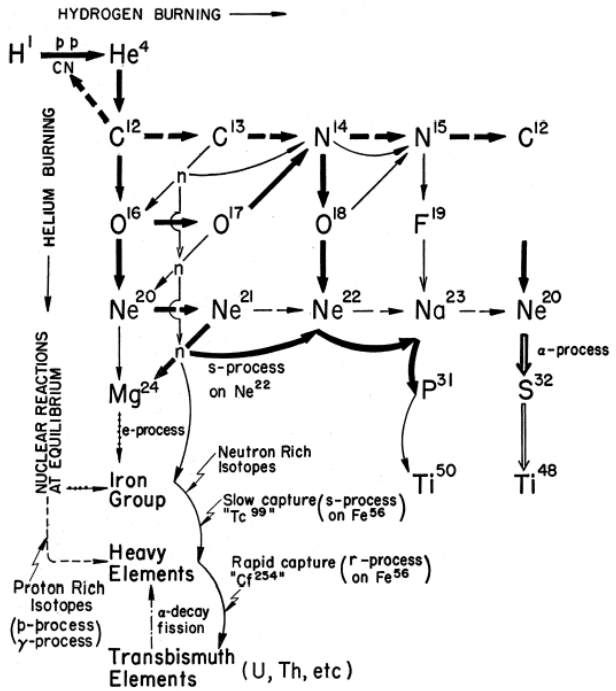
Cassiopeia A (Cas A).
Source: Chandra X-ray Observatory,
NASA/CXC/SAO/Rutgers/J.Hughes



Nuclear Reaction Network in Science (cont)

Nuclear reaction network in high mass stars



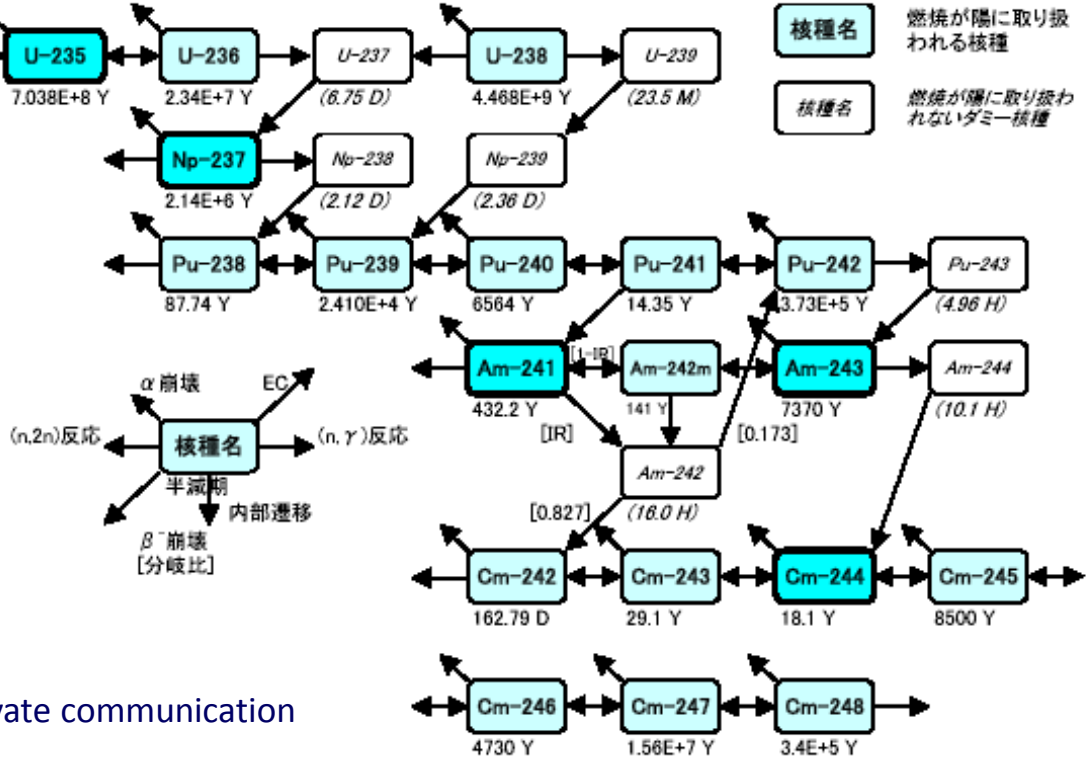


E. M. Burbidge et al., (B^2FH) Rev.Mod.Phys.29(1957)

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

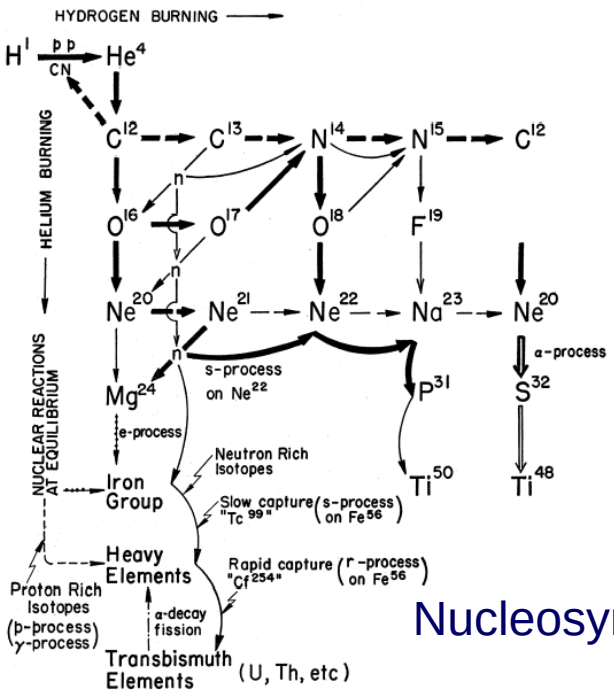
Increase by decay into the i-th isotope

Decrease by reaction from the i-th isotope

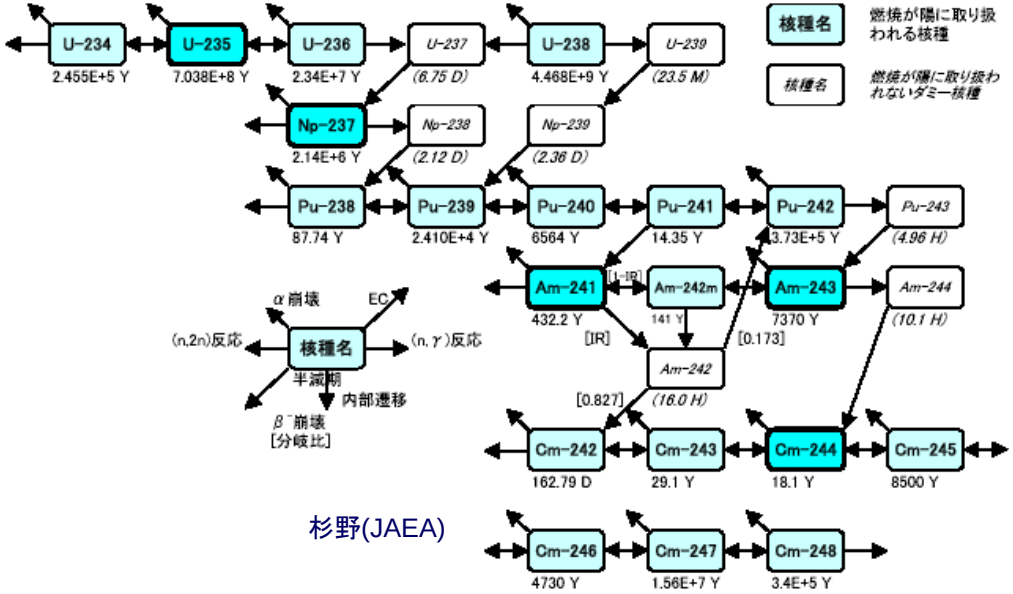
Decrease by decay of the i-th isotope

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

Goal of Nuclear Data



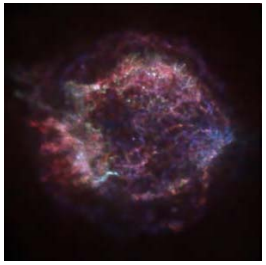
Nucleosynthesis

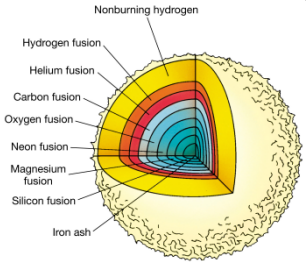


杉野(JAEA)

Burning chain in reactors

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





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

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

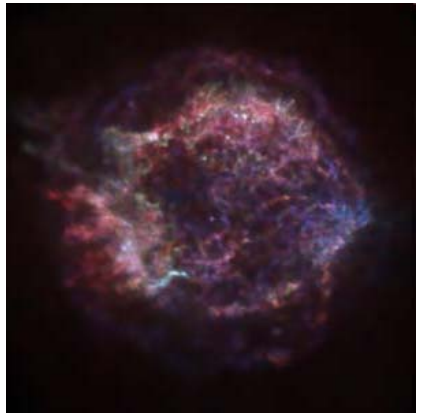
Nuclear Data:
Comprehensive set of nuclear structure and reaction data to solve various nuclear systems

Nuclear Data in Science and Technology

Science

- Nuclear physics
- Astrophysics

etc.



Technology

- Fission and fusion energies
- Material analysis
- Medical application

etc.

Structure Data and Reaction Data

Nuclear Data:

***Data which characterize properties and phenomena of nucleus* (e.g., mass, spin-parity, half-life, cross section)**

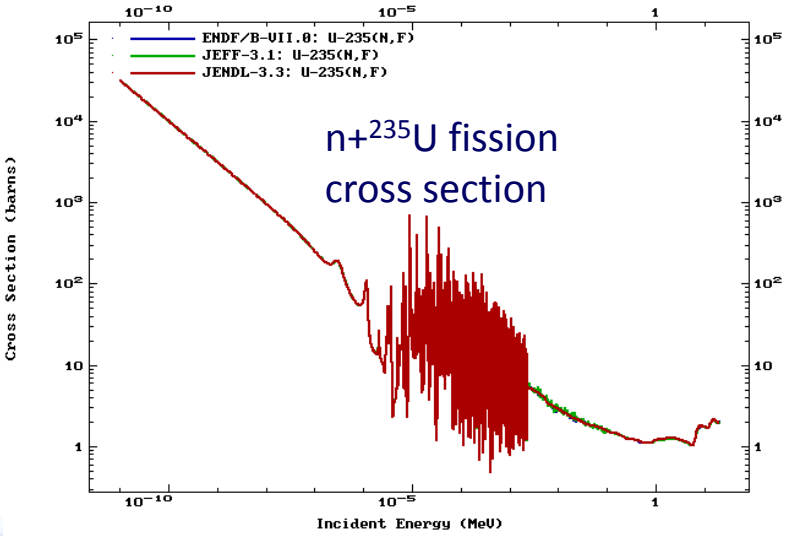
Example: Uranium-235

Mass: 218 942 MeV/c^2

Structure

Level energy (MeV)	Spin	Parity	Half-life
0.0	7/2	-1	7.0×10^8 y
0.0765	1/2	+1	~26 min
13.04	3/2	+1	0.50 ns
…	…		…

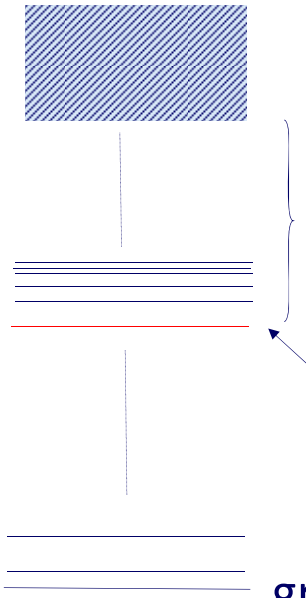
Reaction (incl. EXFOR)



Example of Experimental Data in Library

Fission cross section in resonance region

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

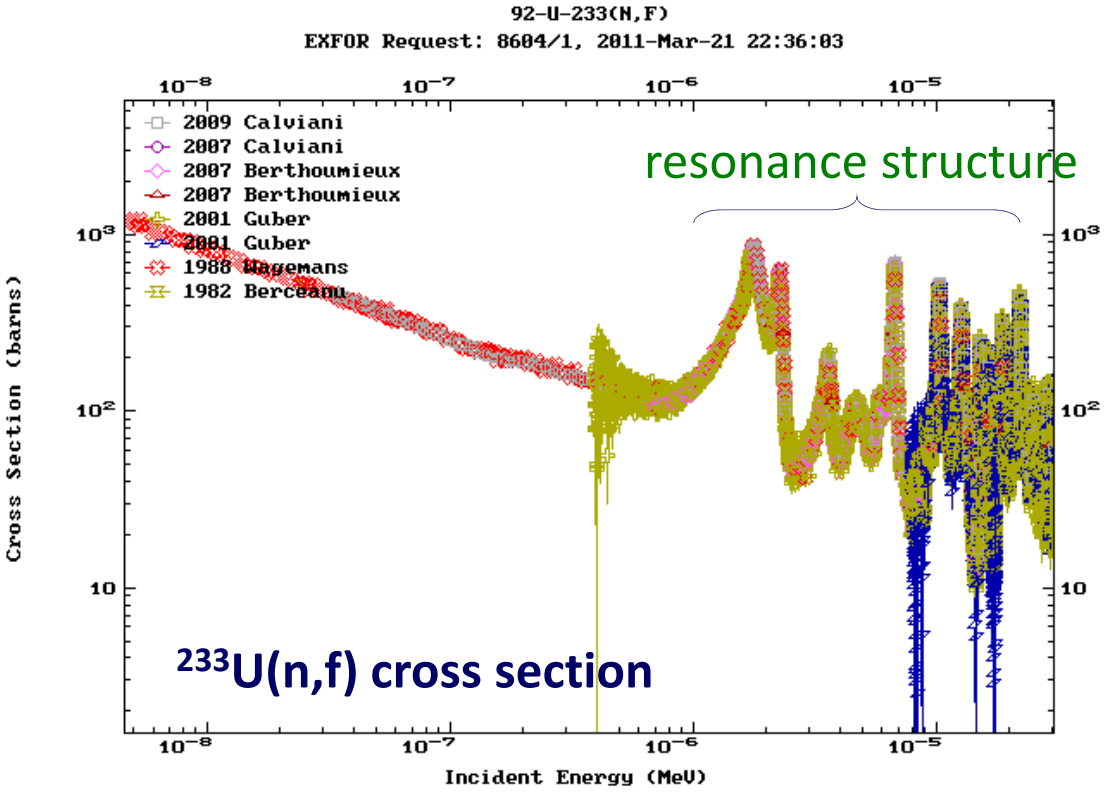


Structure visible by neutron induced reaction

S_n=6.8 MeV

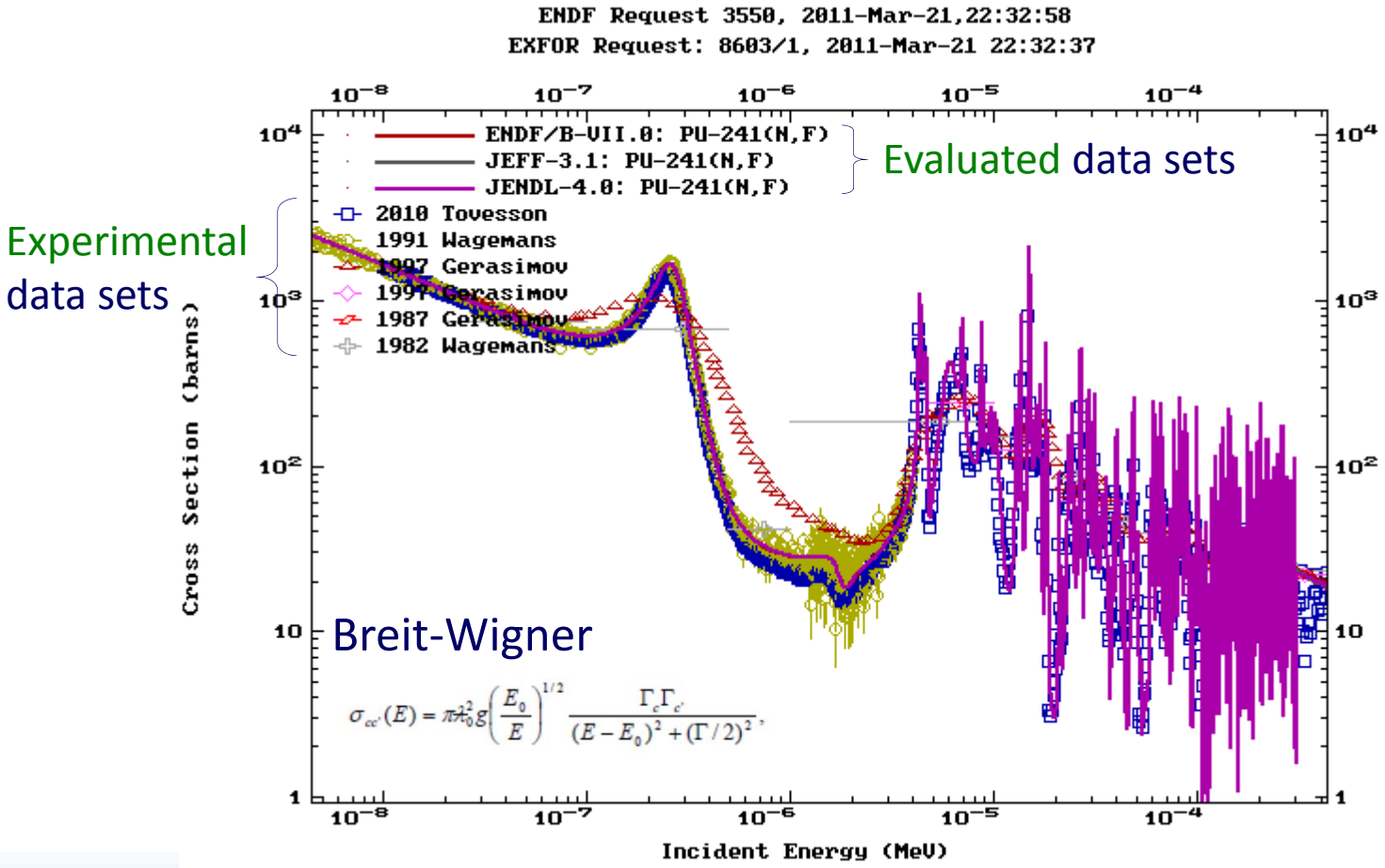
ground state

$^{234}U=n+^{233}U$

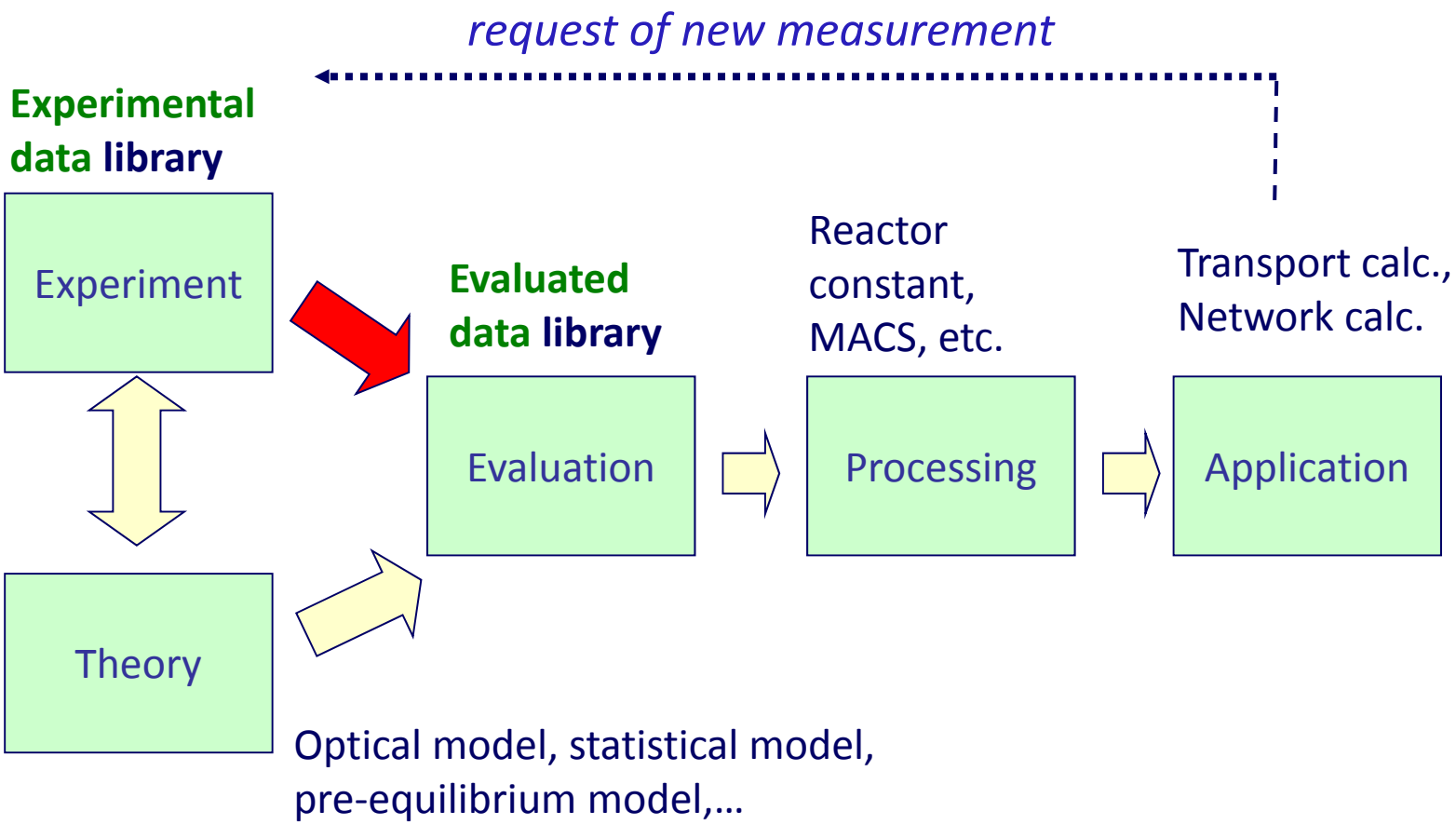


Experimental and Evaluated Data Libraries

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



From Microscopic Experiment to Application



International Atomic Energy Agency

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Department of Physics, Bangalore University, Bangalore, India

20–24 January 2015

Introduction to IAEA Nuclear Data Services

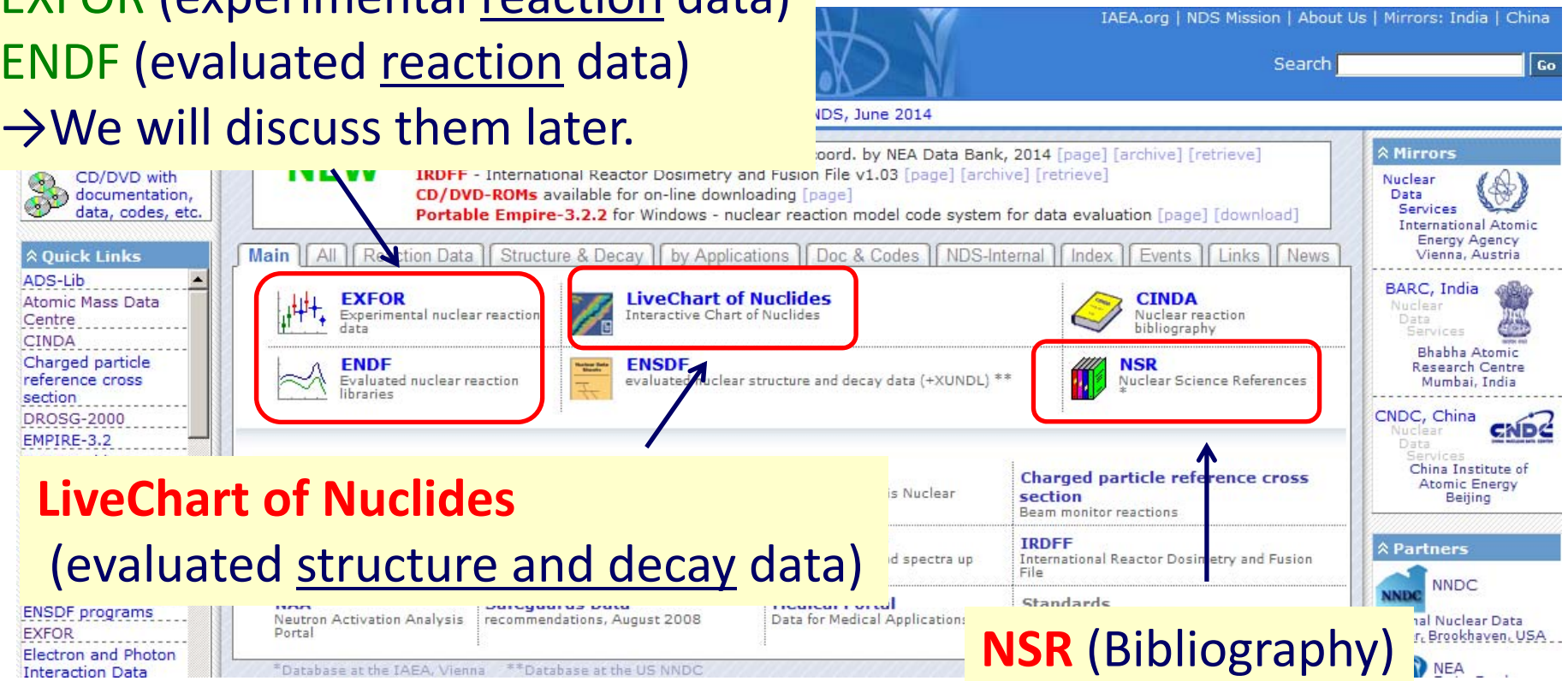
Naohiko OTSUKA

Nuclear Data Section

Department of Nuclear Sciences and Applications

IAEA Nuclear Data Services

EXFOR (experimental reaction data)
ENDF (evaluated reaction data)
→We will discuss them later.

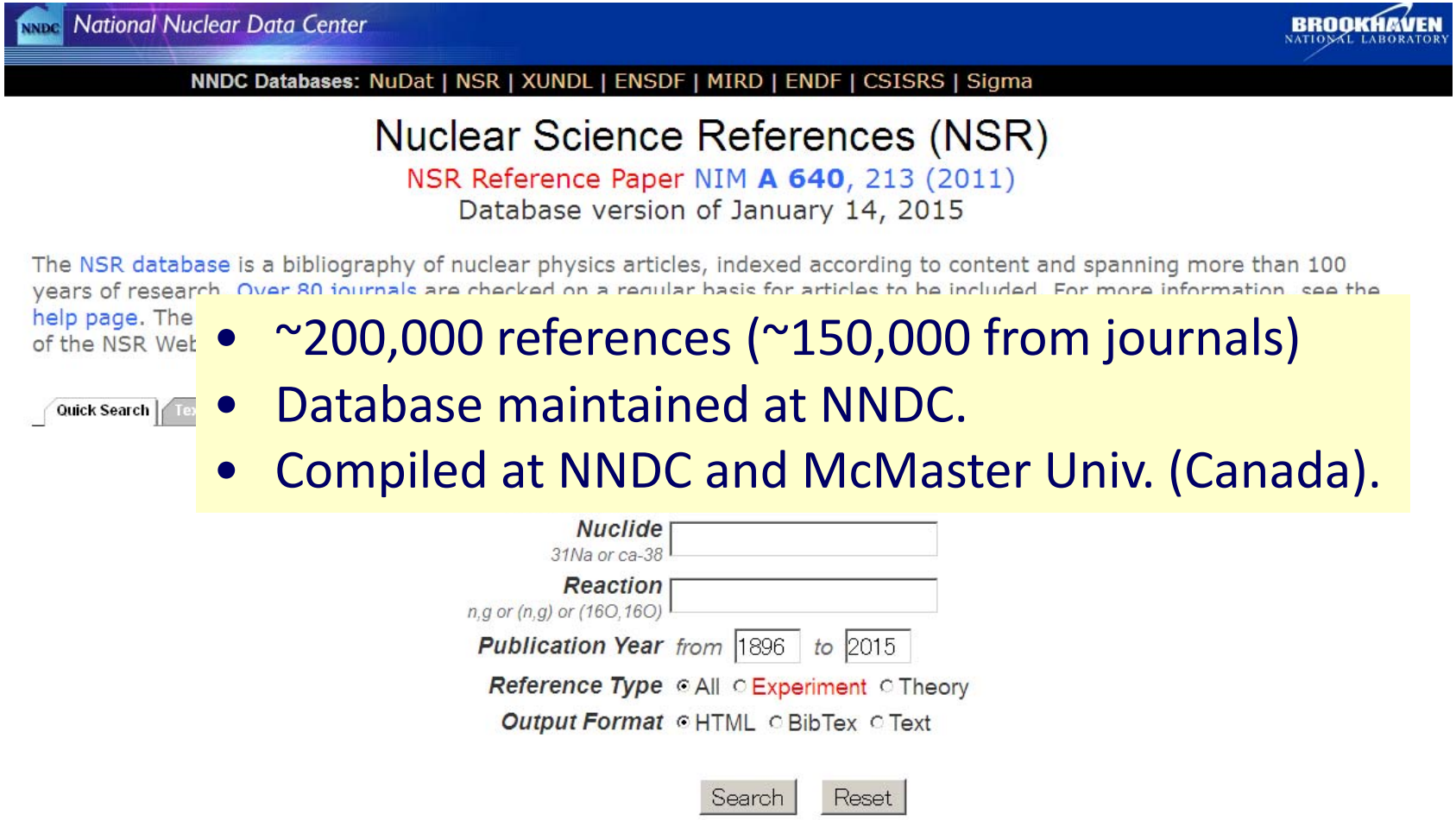


LiveChart of Nuclides
(evaluated structure and decay data)

NSR (Bibliography)

http://www-nds.iaea.org/ : primary server (Vienna)
http://www-nds.indcentre.org.in/: mirror server (India)

NSR (Nuclear Science References)



- ~200,000 references (~150,000 from journals)
- Database maintained at NNDC.
- Compiled at NNDC and McMaster Univ. (Canada).

http://www.nndc.bnl.gov/nsr/

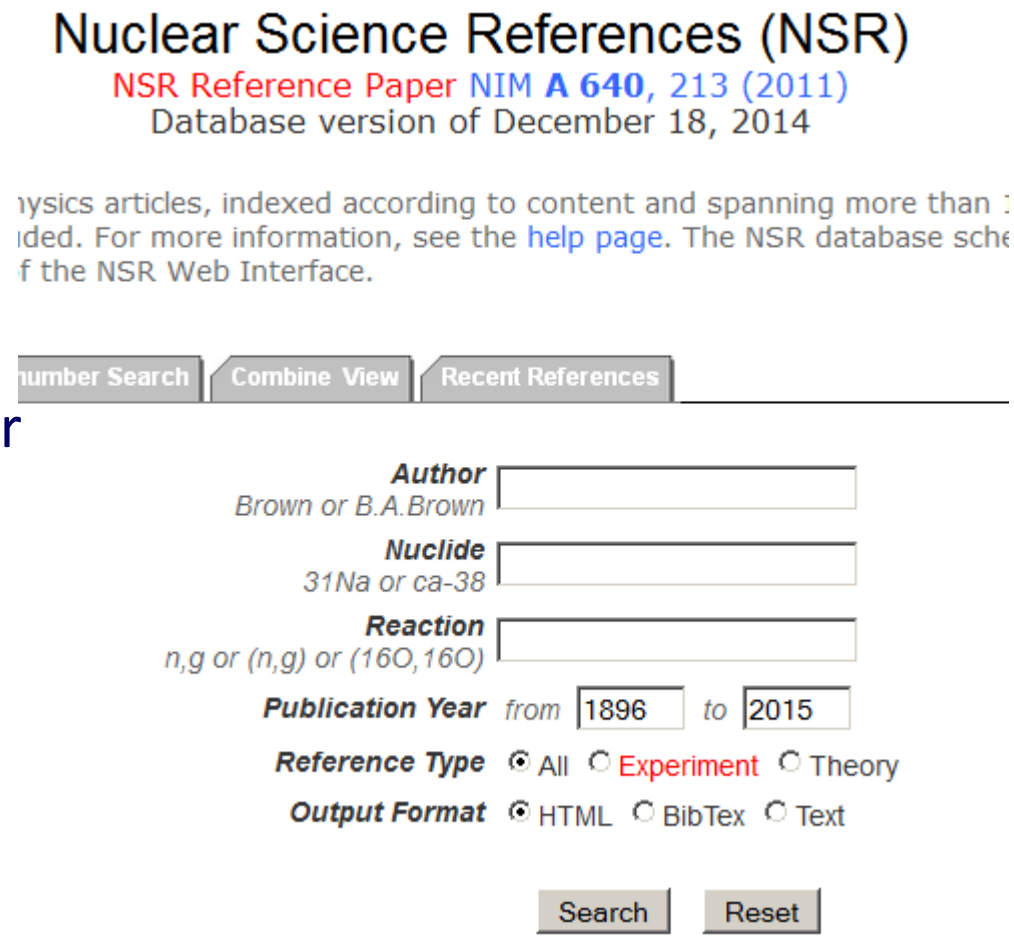
NSR (cont.)

Very easy to use!

Just provide

- Author and/or
- Nuclide (Target) and/or
- Reaction

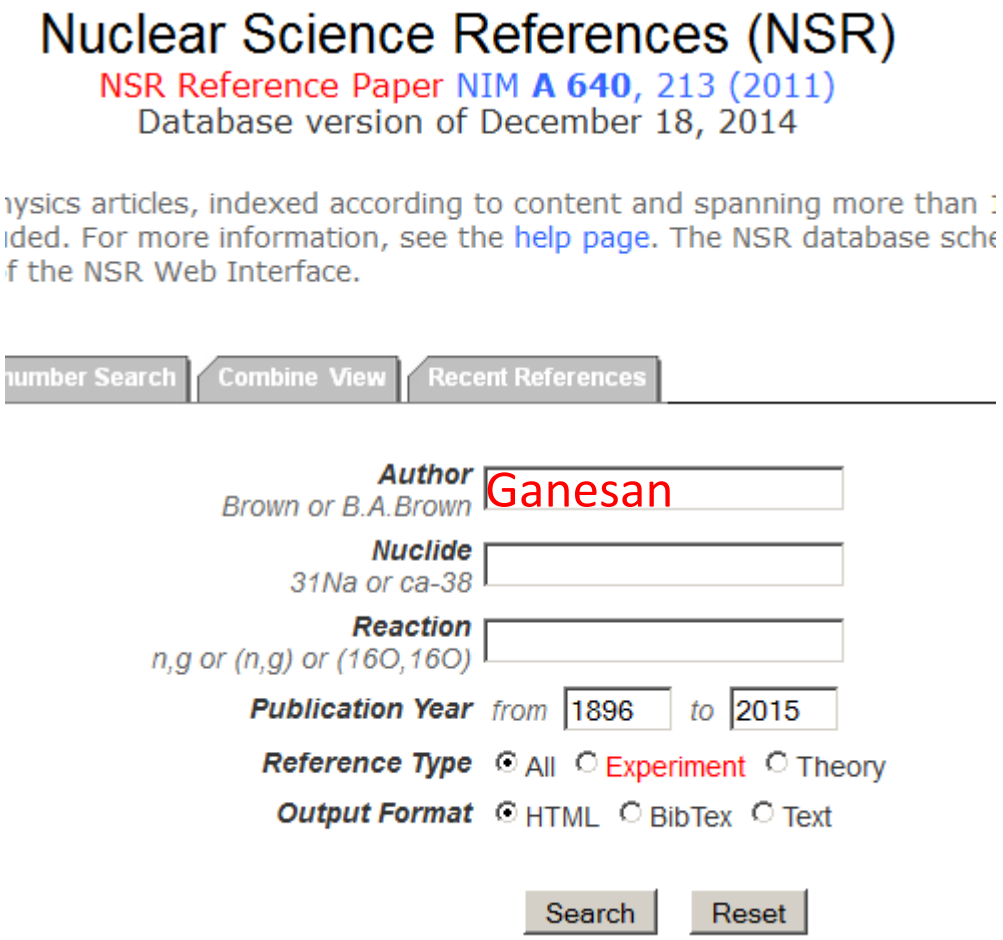
and search.



NSR – Exercise 1

Question

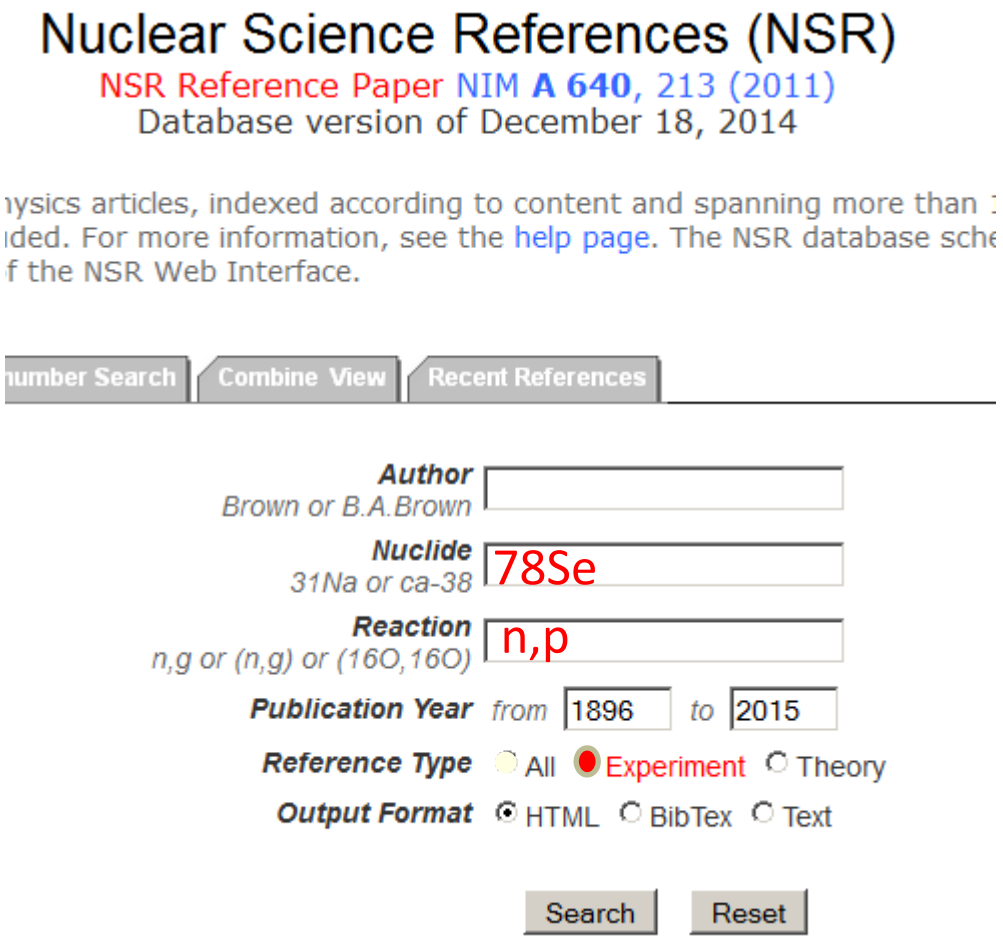
Search articles where "Ganesan" is an author.



NSR – Exercise 2

Question

Search articles reporting experimental results of $^{78}Se(n,p)^{78}As$.



NSR – Exercise 2 (cont)

Not all articles report the ^{78}Se(n,p) reaction.

1995BI16 Phys.Rev. C52, 2546 (1995)

I.-G.Birn, B.Strohmaier, H.Freiesleben, S.M.Qaim

Isomeric Cross Section Ratios for the Formation of ^{75m,75g}Ge in (n, p), (n, α), and (n, 2n) Reactions from 6 to 15 MeV

NUCLEAR REACTIONS ^{75}As(n, p), ^{78}Se(n, α), ^{76}Ge(n, 2n), E=6-15 MeV; measured σ(E); deduced isomeric cross-section ratio. Activation technique, hyperpure Ge detector. Statistical, precompound model analyses.

No ^{78}Se(n,p) in keywords

doi: 10.1103/PhysRevC.52.2546
*Data from this article have been entered in the **EXFOR** database. For more information, access X4 dataset22291.*

1994BI01 Nucl.Sci.Eng. 116, 125 (1994)

I.Birn, S.M.Qaim

Excitation Functions of Neutron Threshold Reactions on Some Isotopes of Germanium, Arsenic, and Selenium in the 6.3- to 14.7-MeV Energy Range

^{78}Se(n,p) in keywords!

NUCLEAR REACTIONS ^{75}As, ^{74,76,78}Se, ^{72,73,74}Ge(n, p), ^{75}As, ^{78,80}Se(α, α), ^{75}As, ^{70,76}Ge(n, 2n), E=6.3-14.7 MeV; measured σ(E). Activation technique, high resolution γ-spectroscopy. Statistical multi-step model analysis.

NSR – Exercise 2 (cont)

Compare NSR output for

"Nuclide =78Se and Reaction = n,p reaction"

with Fig.3 of the 33080 article.

Five past experiments plotted in Fig.3.

Are they also in the NSR output?

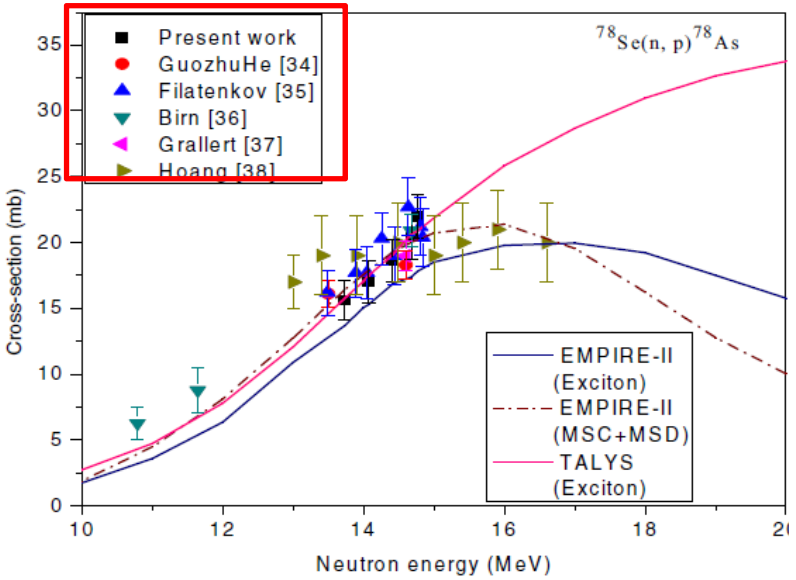


FIG. 3. (Color online) Cross sections for ^{78}Se(n, p)^{78}As reaction

[34] Guozhu He, Zhongjie Liu, Junhua Luo, and Xiangzhong Kong, Indian J. Pure Appl. Phys. **43**, 729 (2005). — Not in NSR

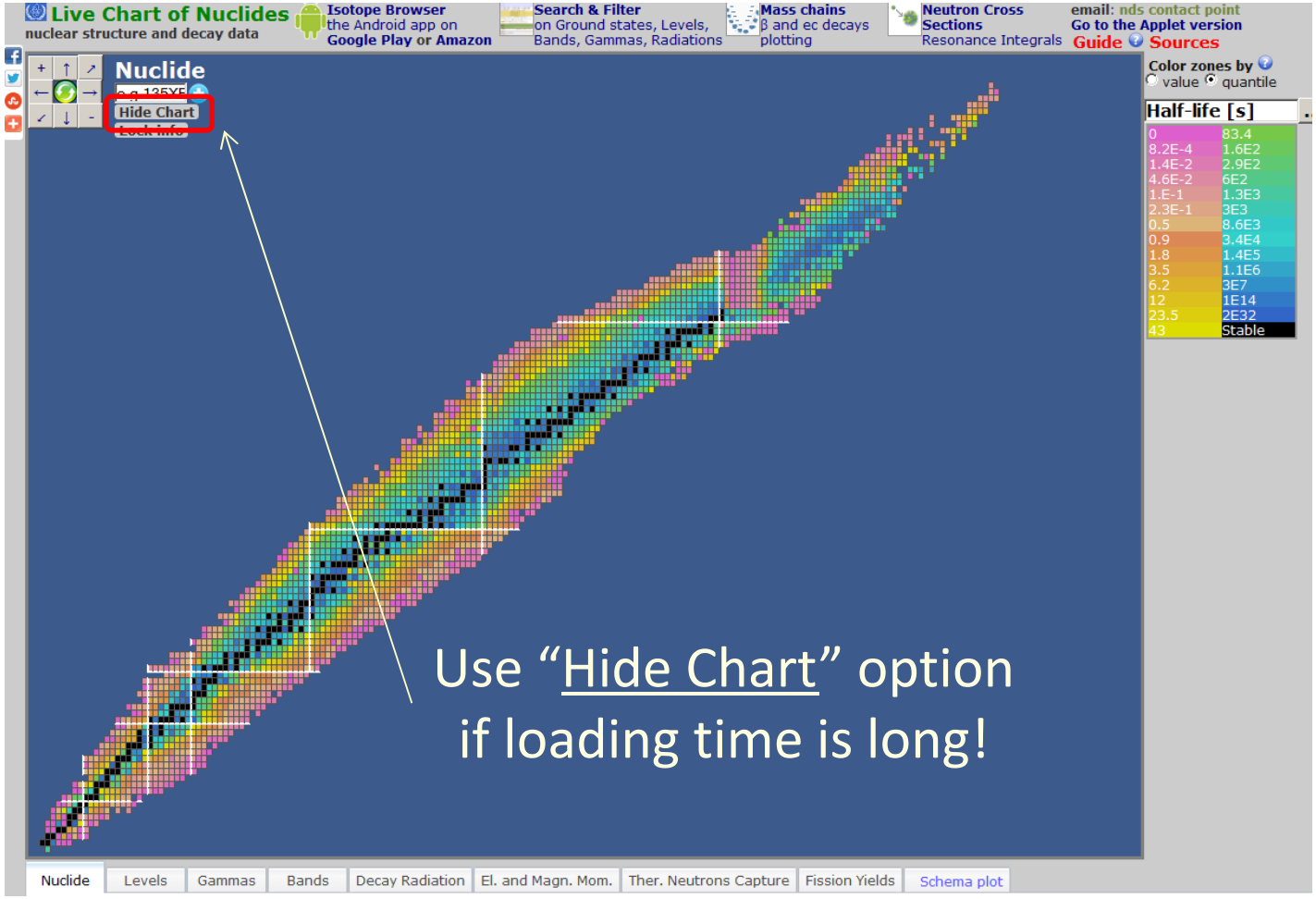
[35] A. A. Filatenkov and S. V. Chuvaev, Khlopin Radiev. Inst., Leningrad Reports No. 258 (2001). — Not in NSR

[36] I. Birn, S. M. Qaim, B. Strohmaier, and H. Freiesleben, Nucl. Sci. Eng. **116**, 125 (1994). — **in NSR**

[37] A. Grallert, J. Csikai, Cs. M. Buczko, and I. Shaddad, IAEA Nucl. Data Section report to the I.N.D. C. No.286, 131 (1993). — Not in NSR

[38] H. M. Hoang, U. Garuska, A. Marcinkowski, and B. Zwieglinski, Zeitschrift fuer Physik A, Hadrons and Nuclei **334**, 285 (1989). — **in NSR**

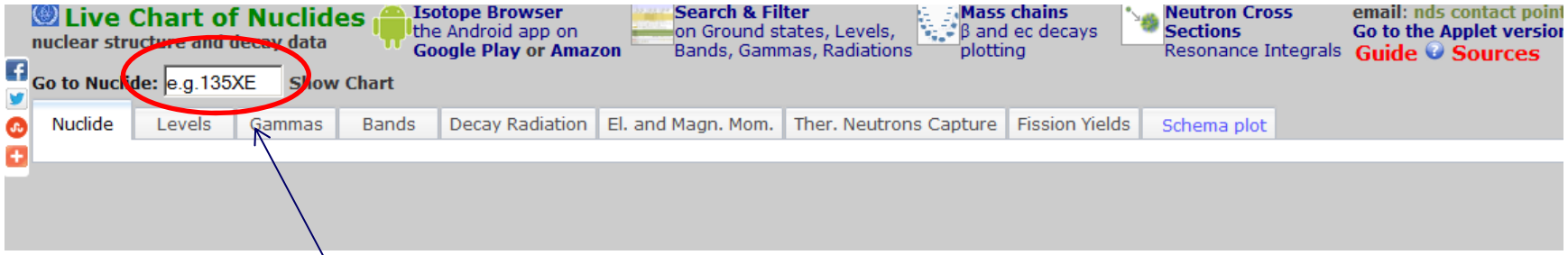
LiveChart of Nuclides



http://www-nds.iaea.org/livechart/ (No mirror available)

LiveChart of Nuclides (cont.)

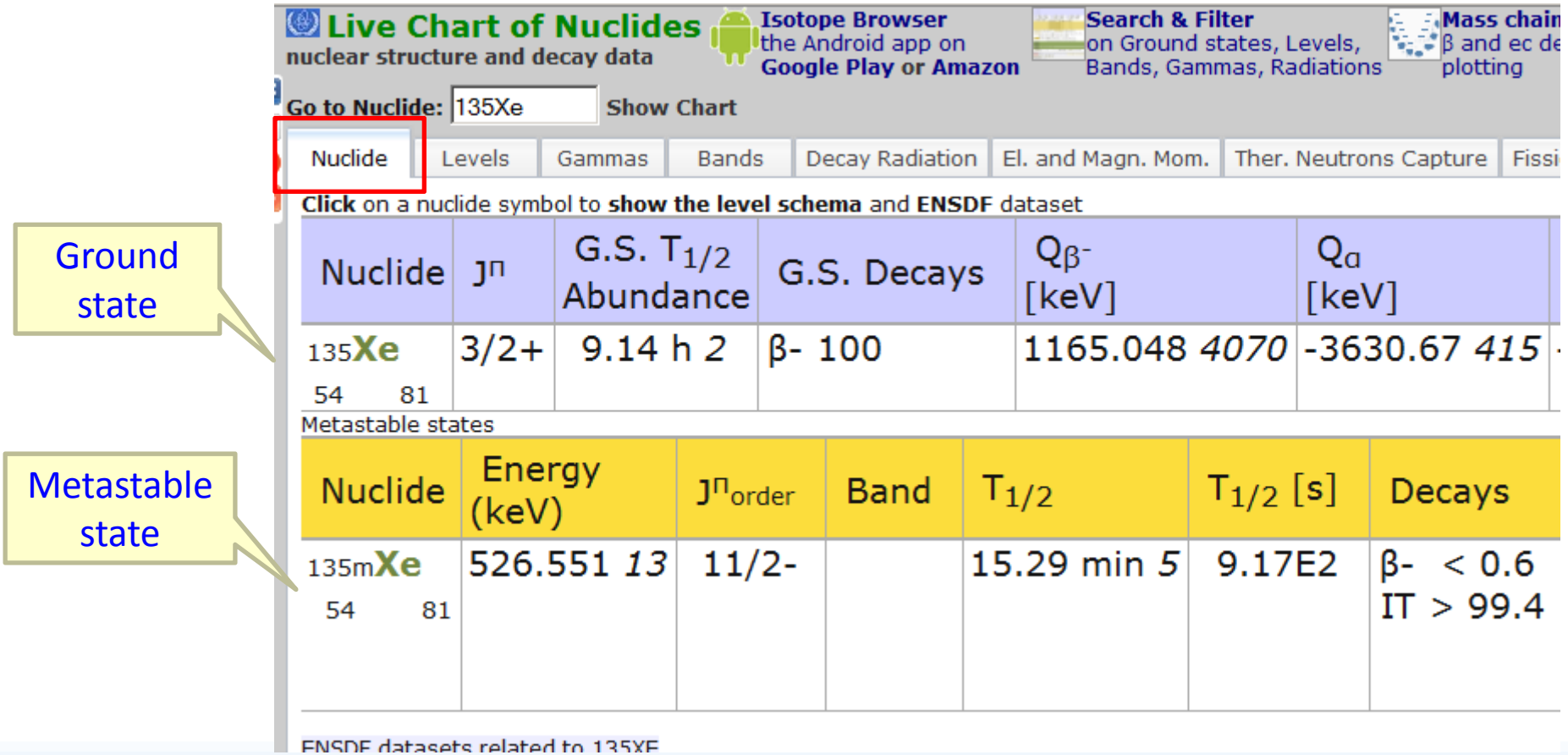
The query page becomes very simple if you select "Hide Chart" option.



Just type a nuclide symbol
(e.g., 1H, 12C, 238U)

LiveChart of Nuclides – ^{135}Xe

Nuclide tab



Ground state

Metastable state

LiveChart of Nuclides - ^{135}Xe (cont.)

Levels tab

Live Chart of Nuclides
nuclear structure and decay data

Isotope Browser
the Android app on
Google Play or Amazon

Search & Filter
on Ground states, Levels,
Bands, Gammas, Radiations

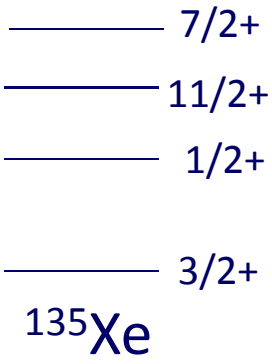
Mass chains
β and ec decays
plotting

Go to Nuclide: 135Xe Show Chart

Nuclide | Levels | Gammas | Bands | Decay Radiation | El. and Magn. Mom. | Ther. Neutrons Capture | Fission Yields | Schem

Click on a nuclide symbol to **show the level schema** and **ENSDF** dataset

Nuclide	Energy (keV)	J^{π} order	Band	$T_{1/2}$	$T_{1/2}$ [s]	Decays
$^{135}_{54}Xe_{81}$	0.0	3/2+		9.14 h *2*	3.29E4	β- 100
$^{135}_{54}Xe_{81}$	288.455 *15*	1/2+				
$^{135}_{54}Xe_{81}$	526.551 *13* m	11/2-		15.29 min *5*	9.17E2	β- < 0.6 IT > 99.4
$^{135}_{54}Xe_{81}$	1131.512 *11*	7/2+				
$^{135}_{54}Xe_{81}$	1260.416 *13*	5/2+				
$^{135}_{54}Xe_{81}$	1448.36 *3*	(3/2+)				



LiveChart of Nuclides - ^{135}Xe (cont.)

Decay Radiation tab

Live Chart of Nuclides
nuclear structure and decay data

Isotope Browser
the Android app on
Google Play or Amazon

Search & Filter
on Ground states, Levels,
Bands, Gammas, Radiations

Mass chains
β and ec decays
plotting

Go to Nuclide: 135Xe Show Chart

Nuclide | Levels | Gammas | Bands | Decay Radiation | El. and Magn. Mom. | Ther. Neutrons Capture | Fission Yields

Parent	$T_{1/2}$	Level E [keV]	Jp order	Decay	Q decay note on Q values	Daughter
^{135}Xe 54 81	9.14 h *2*	0.0	3/2+	β- 100 %	1165.048 *4070*	^{135}Cs 55 80

see the ENSDF source

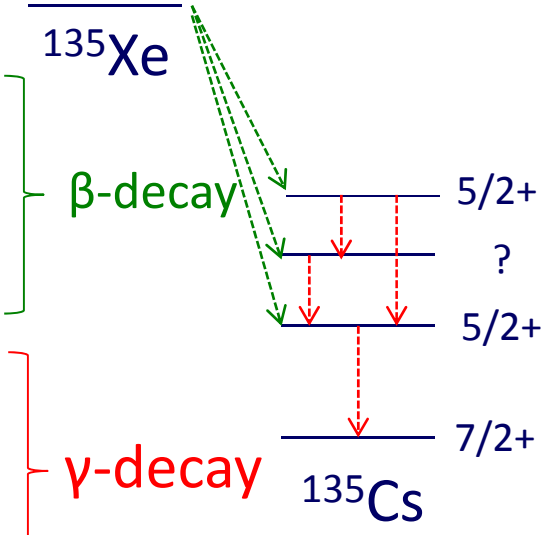
Note: Q-value used in ENSDF to determine displayed decay data is: 1165 *4* keV - see note on Q values

Beta -

Fed level [keV]	Jp	End Point [keV]	Avg Energy [keV]	Intens. per decay [%
1062.420 *14*		103 *4*	26.9 *11*	0.123 *6*
981.315 *22*		184 *4*	50.0 *12*	0.075 *5*
608.186 *14*	5/2+	557 *4*	173.3 *15*	3.11 *14*
407.989 *13*		757 *4*	248.1 *16*	0.59 *3*
249.793 *12*	5/2+	915 *4*	310.2 *16*	96 *4*

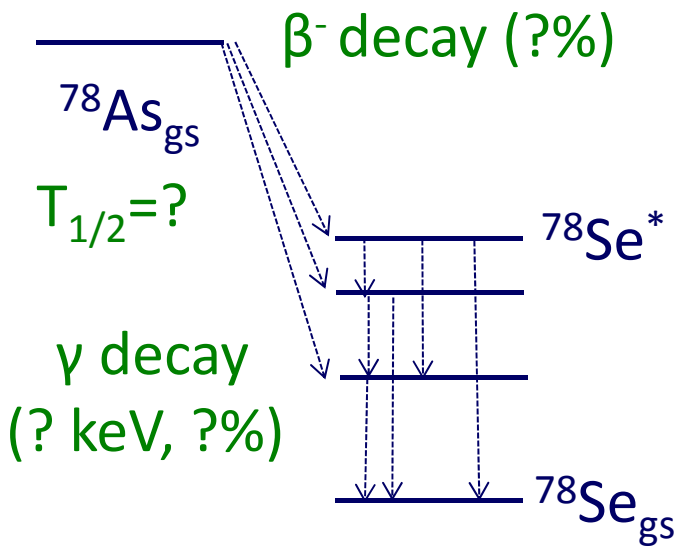
Gamma

Start level [keV]	Jp	Final Level [keV]	Jp	γ Energy [keV]	Intens. per de
407.989 *13*		249.793 *12*	5/2+	158.197 *18*	0.289 *14*
608.186 *14*	5/2+	407.989 *13*		200.19 *10*	0.012 *5*
249.793 *12*	5/2+	0.0	7/2+	249.794 *15*	90 *3*
608.186 *14*	5/2+	249.793 *12*	5/2+	358.39 *3*	0.221 *11*
981.315 *22*		608.186 *14*	5/2+	373.13 *10*	0.015 *3*



LiveChart of Nuclides - Exercise

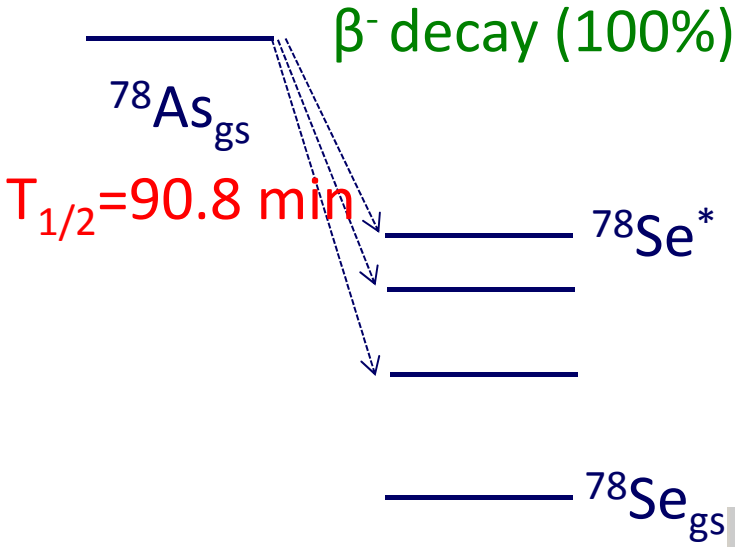
One determined the $^{78}Se(n,p)^{\mathbf{78}}\mathbf{As}$ cross section by detection of γ from ^{78}As - β^- decay → $^{78}Se^*$- γ decay→$^{78}Se_{gs}$.



Questions:

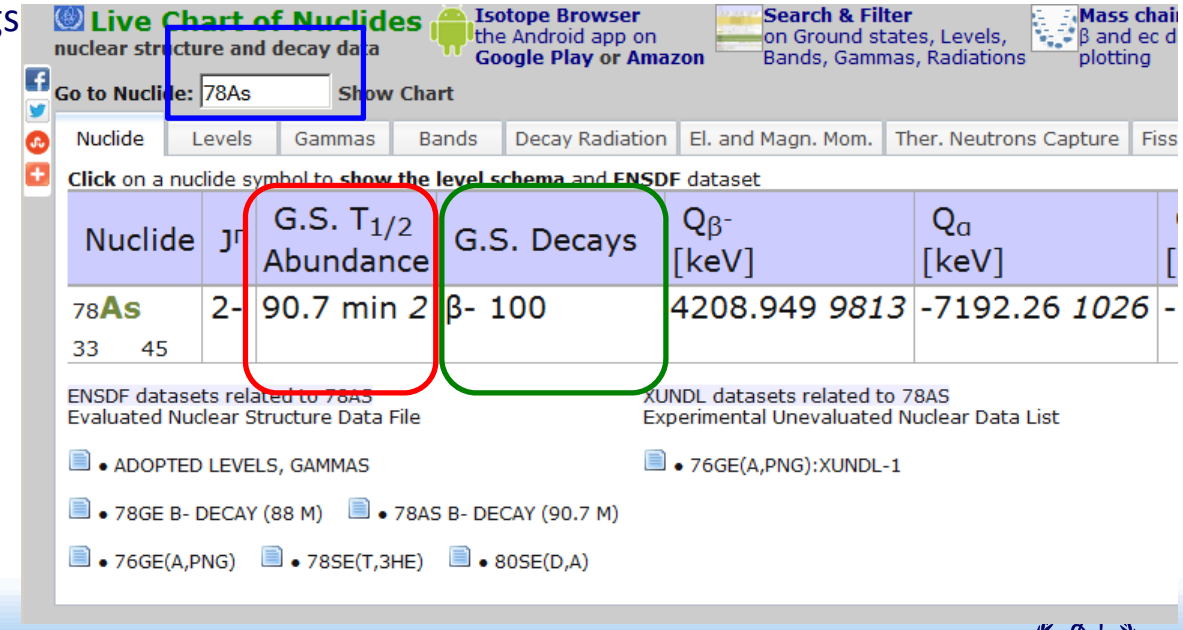
1. Half-life of ^{78}As
2. Branching ratio of ^{78}As β^- decay
3. Energy of strongest decay γ radiation and its intensity

LiveChart of Nuclides – Exercise (cont)

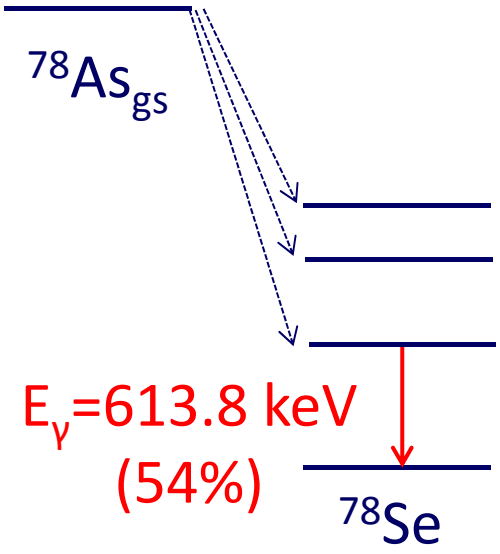


Questions:

1. **Half-life of ^{78}As**
2. **Branching ratio of ^{78}As β- decay**
3. Energy of strongest decay γ radiation and its intensity



LiveChart of Nuclides – Exercise (cont)



Questions:

1. Half-life of ^{78}As
2. Branching ratio of ^{78}As β^- decay
3. **Energy of strongest decay γ radiation and its intensity**

Live Chart of Nuclides
nuclear structure and decay data

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Mass chains
β and ec decays
plotting

Go to Nuclide: 78As Show Chart

Nuclide | Levels | Gammas | Bands | Decay Radiation | El. and Magn. Mom. | Ther. Neutrons Capture | Fission Yields

Level | Jp | note on

Gamma

Start level [keV]	Jp	Final Level [keV]	Jp	γ Energy [keV]	Intens. per de
2838.58 *9*	(2+)	2682.09 *9*	4+	156.6 *3*	0.092 *24*
2682.09 *9*	4+	2507.72 *10*	3-	174.2 *3*	0.18 *4*
1854.00 *9*	3+	1502.64 *11*	4+	351.1 *2*	0.162 *24*
2682.09 *9*	4+	2327.34 *13*	2+	354.3 *2*	1.9 *3*
1758.91 *11*	0+	1308.66 *7*	2+	449.8 *4*	0.08 *3*
3144.52 *13*	3-	2682.09 *9*	4+	462.2 *2*	0.59 *9*
1995.78 *10*	2+	1498.76 *18*	0+	497.0 *3*	0.18 *3*
2838.58 *9*	(2+)	2334.87 *19*	0+	503.7 *2*	0.42 *6*
~~1854.00 *9*~~	~~3+~~	~~1308.66 *7*~~	~~2+~~	~~545.3 *1*~~	~~3.0 *4*~~
613.84 *7*	2+	0.0	0+	613.8 *1*	**54 *6***
3144.52 *13*	3-	2507.72 *10*	3-	637.1 *2*	0.21 *3*

LiveChart of Nuclides – Exercise (cont)

Half-lives and decay gamma intensities are important inputs to derive Activation cross sections.

Extractions from the 33080 article ($\lambda=\ln 2/T_{1/2}$, f_d: decay γ intensity)

$$\sigma = \sigma_M \frac{A\varepsilon_M}{A_M\varepsilon} \frac{f_{dM}\lambda}{f_d\lambda_M} \frac{N_M}{N} \frac{(1-e^{-\lambda_M t_1})}{(1-e^{-\lambda t_1})} \frac{e^{-\lambda_M t_2}}{e^{-\lambda t_2}} \frac{(1-e^{-\lambda_M t_3})}{(1-e^{-\lambda t_3})},$$

We extracted these data from LiveChart.

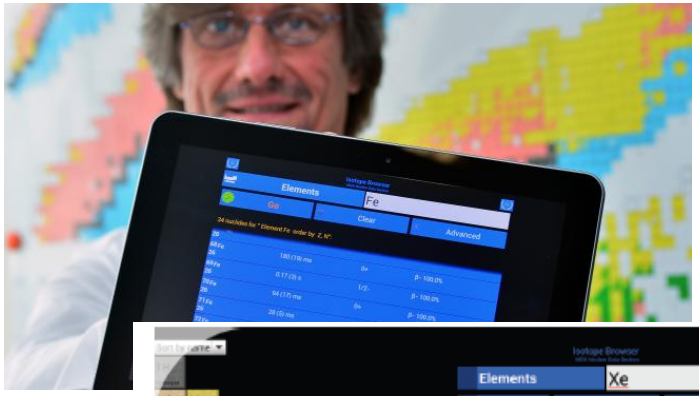
TABLE I. The decay data of the radioisotopes produced

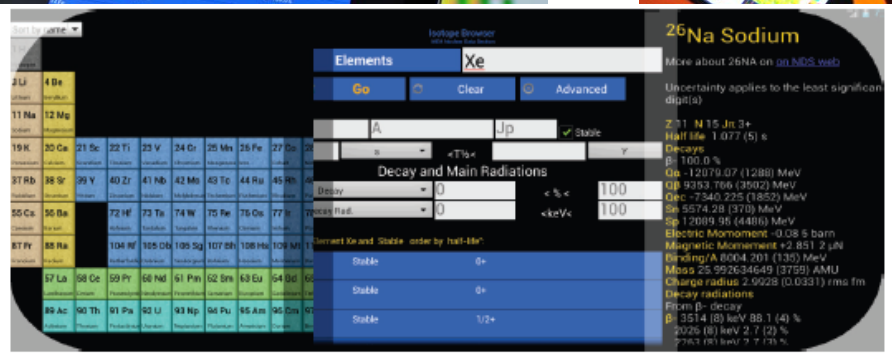
Nuclear Reaction	Abundance (%)	Half life	E_γ (MeV)	f_d (%)
^{78}Se(n, p)^{78}As	23.77 ± 0.28	90.7 ± 0.2 m	0.614	54 ± 0.6
^{80}Se(n, p)^{80}As	49.61 ± 0.41	15.2 ± 0.2 s	0.666	42 ± 0.5
^{56}Fe(n, p)^{56}Mn	91.75 ± 0.36	2.578 ± 0.0001 hr	0.847	99 ± 0.3
^{19}F(n, p)^{19}O	100	26.91 ± 0.08 s	0.197	96 ± 2.1
			1.357	50.4 ± 1.1

LiveChart of Nuclides – Data Source

- Q-value, S-value, atomic masses: 2012 Atomic Mass Evaluation (G. Audi et al., Chin.Phys.C**36**(2012)1287; M. Wang et al., Chin.Phys.C**36**(2012)1603)
- Natural isotopic abundances: M.Berglund and M.E.Wieser, Pure.Appl.Chem.**83**(2011)397.
- Other data are mainly from the ENSDF library which evaluation results are also published in “Nuclear Data Sheets” which is good for citation.
- Similar data can be also available through NuDat (NNDC).

Isotope Browser (Mobile app for iOS and Android)





Free!

Android: Search for “isotope browser” on “Google Play”.

Apple: Search for “isotope browser” on “iTunes”.

Send your feedback to the developer (Dr Marco Verpelli)!