



# International Atomic Energy Agency

The 9th DAE-BRNS Workshop on

**Nuclear Reaction Data and its Compilation for EXFOR Database**

Department of Physics, Bharathiar University, Coimbatore India

14–18 November 2023

## Introduction to IAEA Nuclear Data Services



**Naohiko OTSUKA**



**Nuclear Data Section**

**Department of Nuclear Sciences and Applications**

# Nuclear Data for Safe Rice

**Sinosphere**  
Dispatches From China



## After 'Cadmium Rice,' now 'Lead' and 'Arsenic Rice'

By DIDI KIRSTEN TATLOW APRIL 25, 2014 7:48 AM 56



A farmer works her land near a lead smelter in Hunan Province. Sim Chi Yin for The New York Times

Rice absorb poisonous heavy metallic elements like Cd, As more than other vegetables.

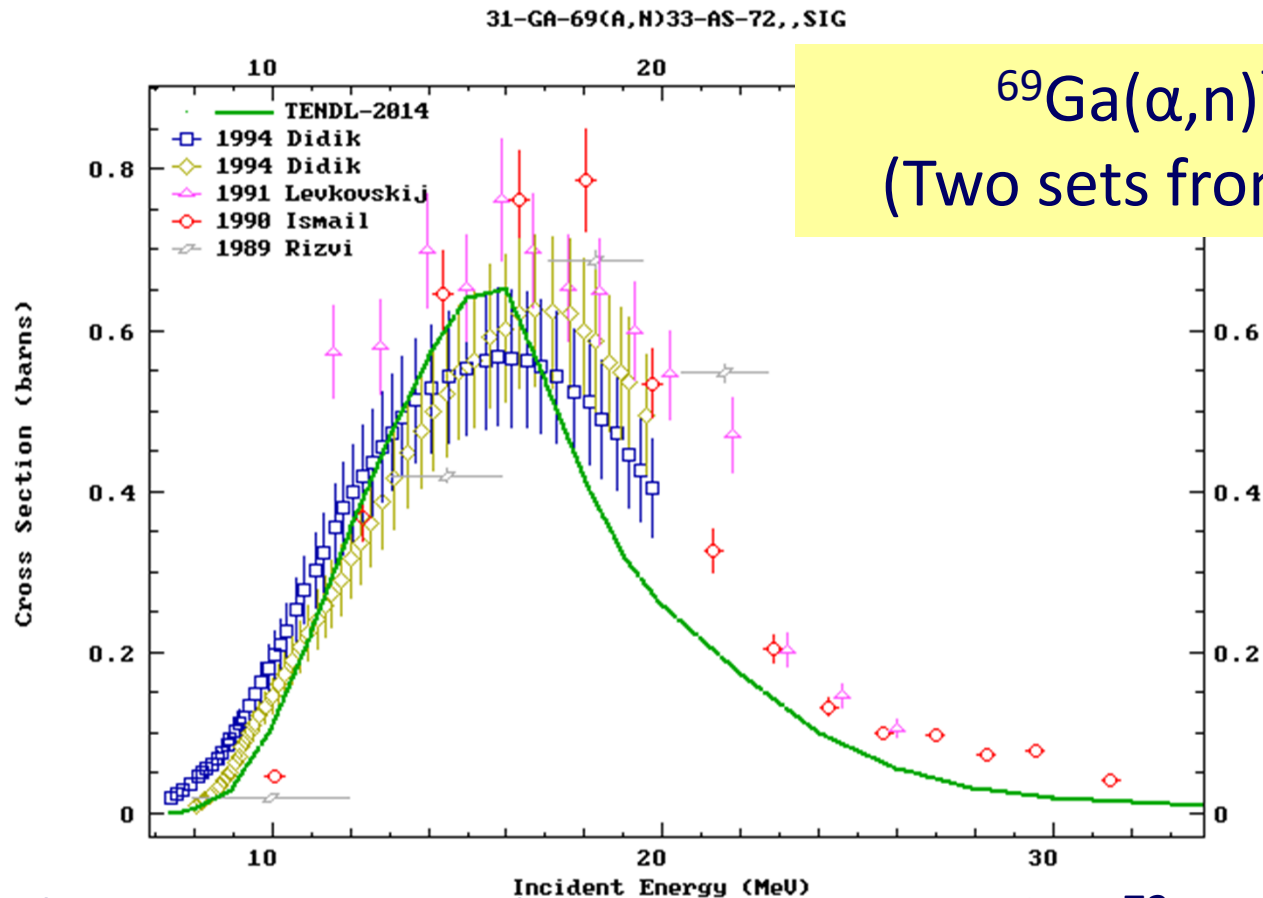
An improved rice against Cd absorption is developed in Japan.

However, this improved rice absorbs more As ☹️

→ Needs of As RI tracer.



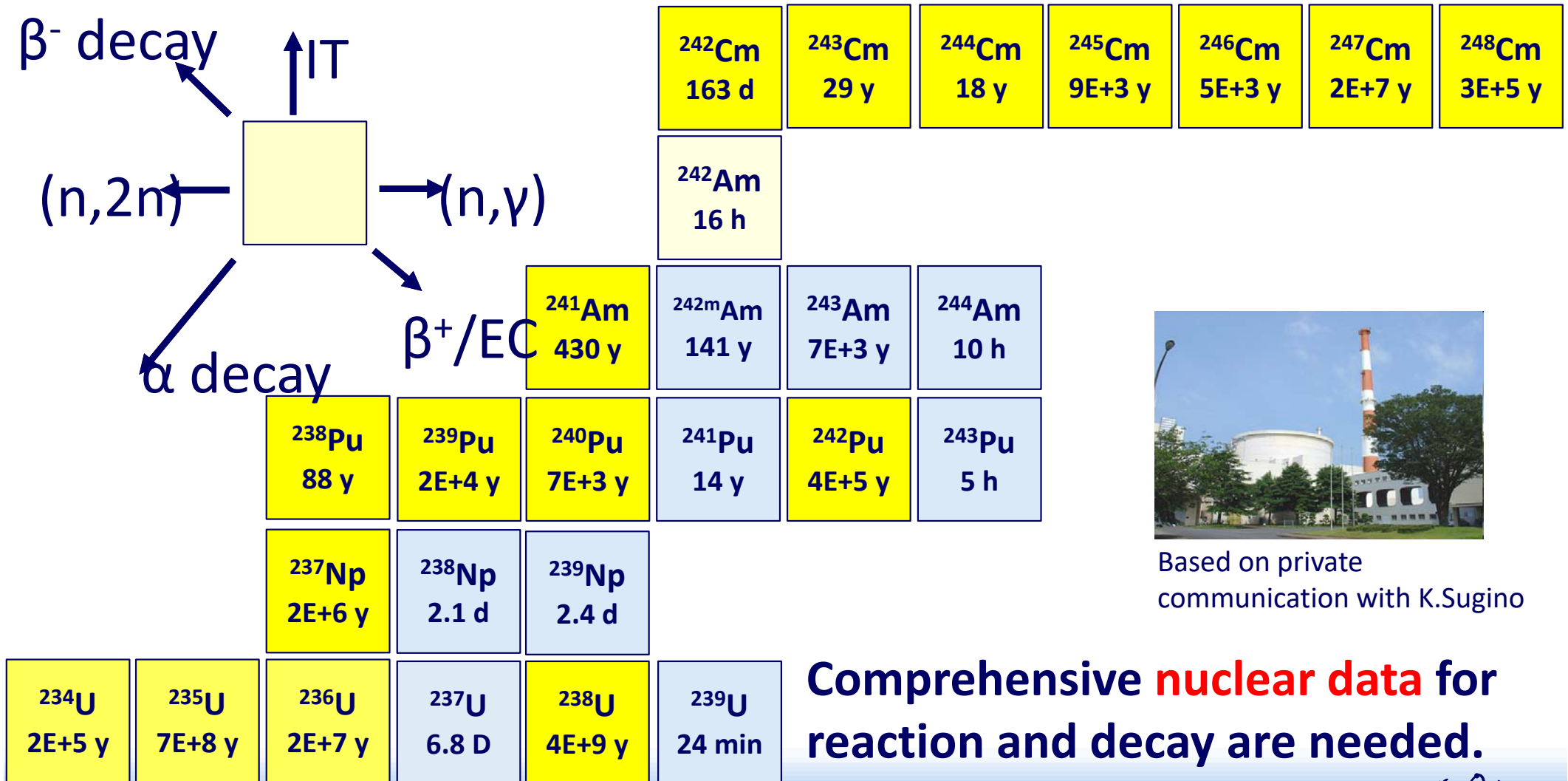
# Nuclear Data for $^{72}\text{As}$ (26 hrs) Tracer Production



- None of these experientialists are interested in  $^{72}\text{As}$  production for application.
- Nevertheless, we can estimate yield and best beam energy without a new experiment **thanks to EXFOR**.

# Nuclear Database for Reaction Network Study (in nuclear engineering)

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

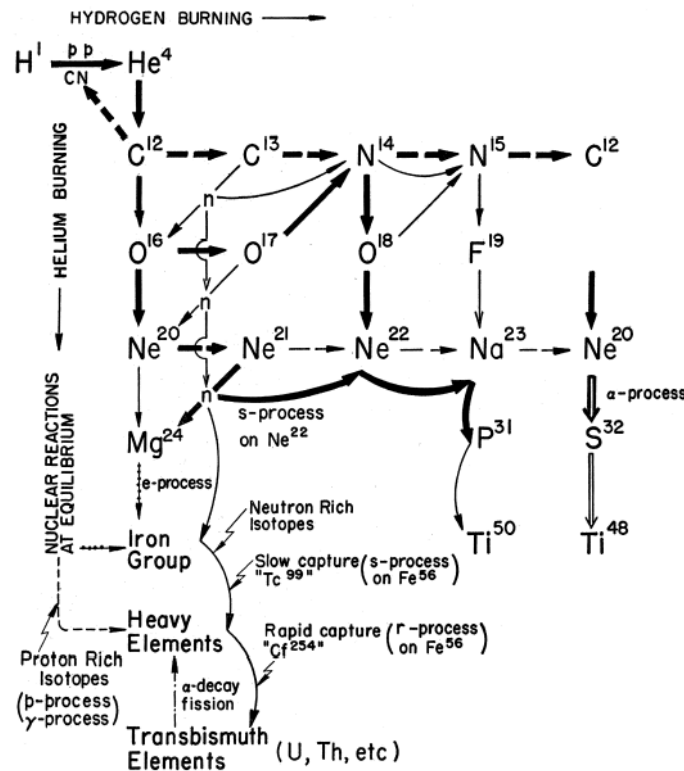
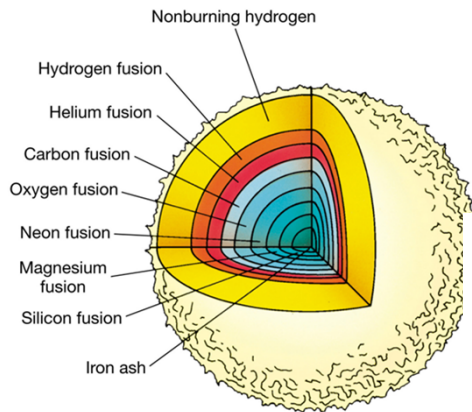


Based on private communication with K.Sugino

**Comprehensive nuclear data for reaction and decay are needed.**



# Nuclear Database for Reaction Network Study (in nuclear science)



## C. General Dynamics of the *s* and *r* Processes

In the buildup of nuclei by the *s* and the *r* processes the reactions which govern both the rate of flow and the track followed in the  $(A, Z)$  plane are the  $(n, \gamma)$  and  $(\gamma, n)$  reactions, beta decay, and, at the ends of the tracks, alpha decay in the case of the *s* process and neutron-induced fission in the case of the *r* process. We denote the rates of the  $(n, \gamma)$ ,  $(\gamma, n)$  and beta process as  $\lambda_n, \lambda_\gamma, \lambda_\beta$ , where

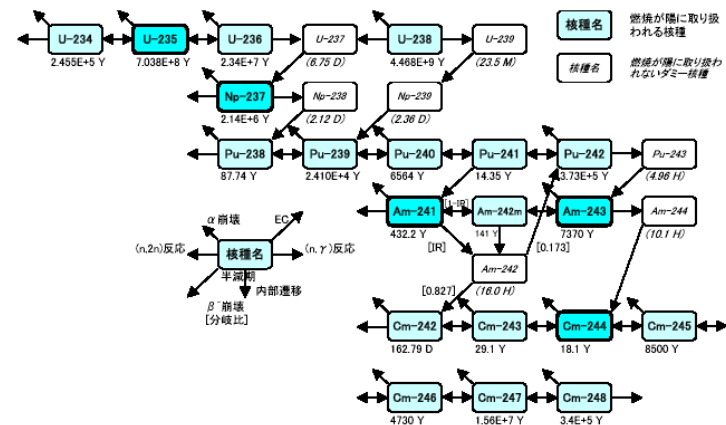
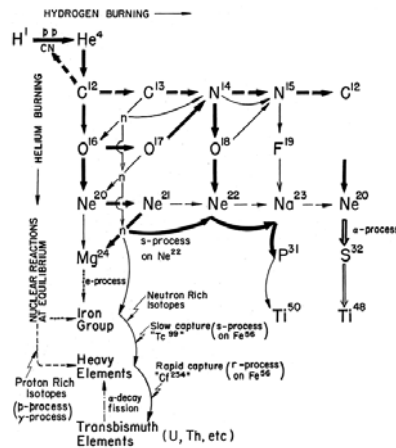
$$\begin{aligned} \lambda_n &= 1/\tau_n = \sigma_n v_n n_n, \\ \lambda_\beta &= 1/\tau_\beta = \text{const}/W_\beta^5, \\ \lambda_\gamma &= 1/\tau_\gamma = \sigma_\gamma c n_\gamma, \end{aligned} \quad (8)$$

and  $\sigma_n$  and  $\sigma_\gamma$  are the cross sections for the  $(n, \gamma)$  and  $(\gamma, n)$  reactions, respectively;  $v_n$  and  $n_n$  are the velocity and density of neutrons responsible for the  $(n, \gamma)$  reactions;  $n_\gamma$  is the density of  $\gamma$  radiation; and  $W_\beta$  is the beta-decay energy.

E. M. Burbidge et al., (B<sup>2</sup>FH) Rev.Mod.Phys.29(1957)

Comprehensive **nuclear data** for reaction and decay are needed.

# Nuclear Data in Bateman Equation



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

$\lambda$ : decay constant ( $=\ln 2/T_{1/2}$ )

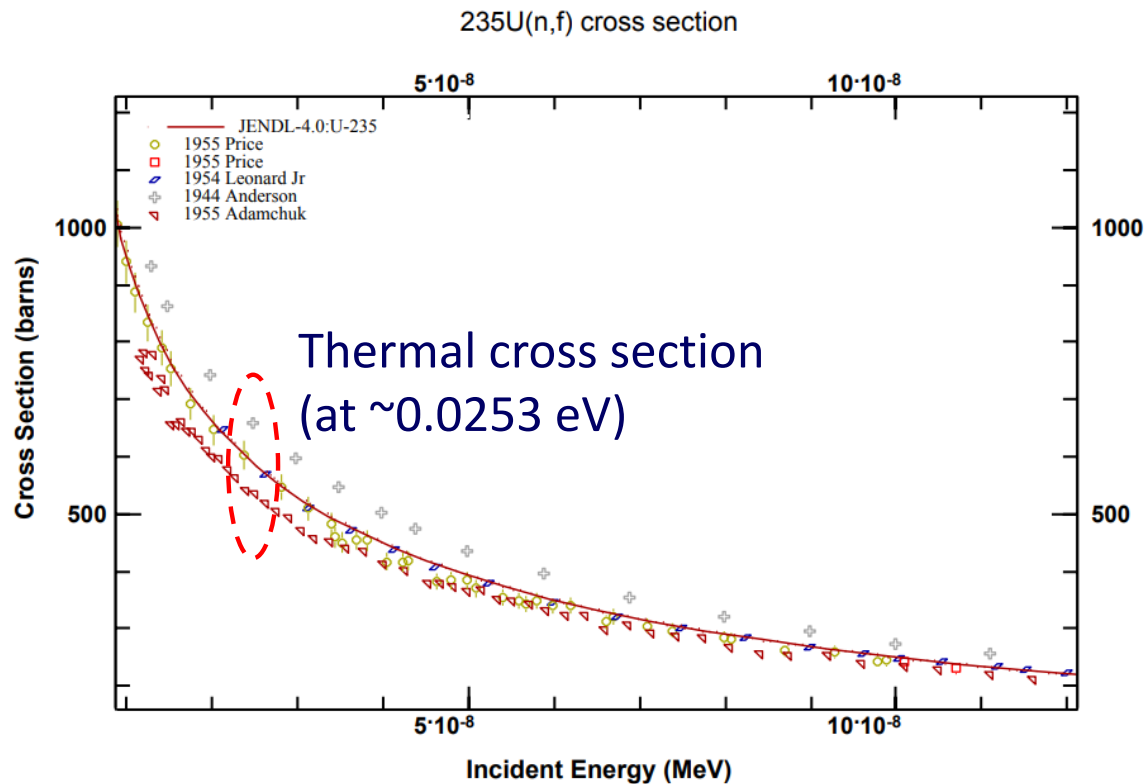
$\sigma$ : cross section

**Collection of nuclear data is necessary.  
(nuclear database)**



# Nuclear Data in the 1950s – “Classified Information”

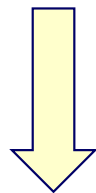
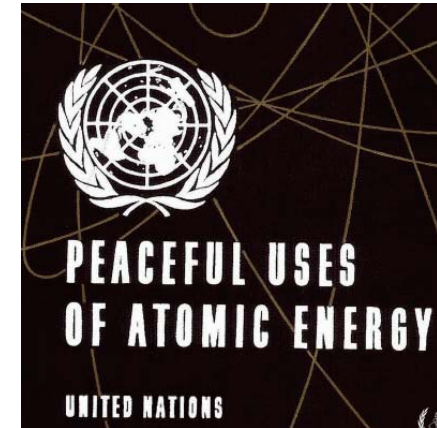
Nuclear data information was classified in the 1950s. Even  $^{235}\text{U}(n_{\text{th}},f)$  cross section was not an well stablished constant.



Experimental data published before 1955 by LANL, Harwell and Dubna.

# UN Geneva Conferences (1955, 1958) - Declassification

An attempt to publicize nuclear data was made among USA, UK and USSR in the 1955 and 1958 Geneva Conferences.



IAEA Nuclear Data Unit (1964)  
IAEA Nuclear Data Section (1970)



Closing session of the 1955 Geneva Conference (President: Homi Bhabha)

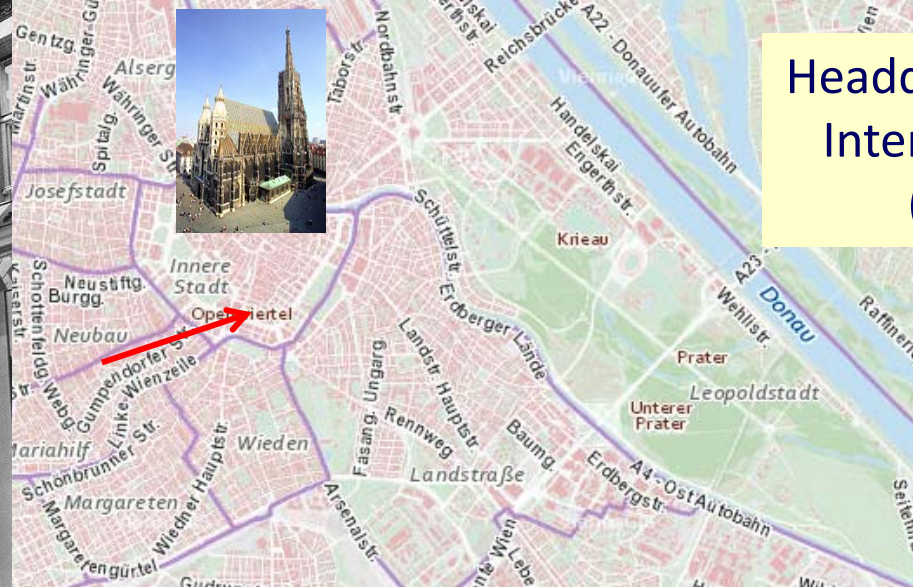


# Where is IAEA?

Headquarters on  
Kärntner Ring  
(1958-1979,  
now Grand Hotel)

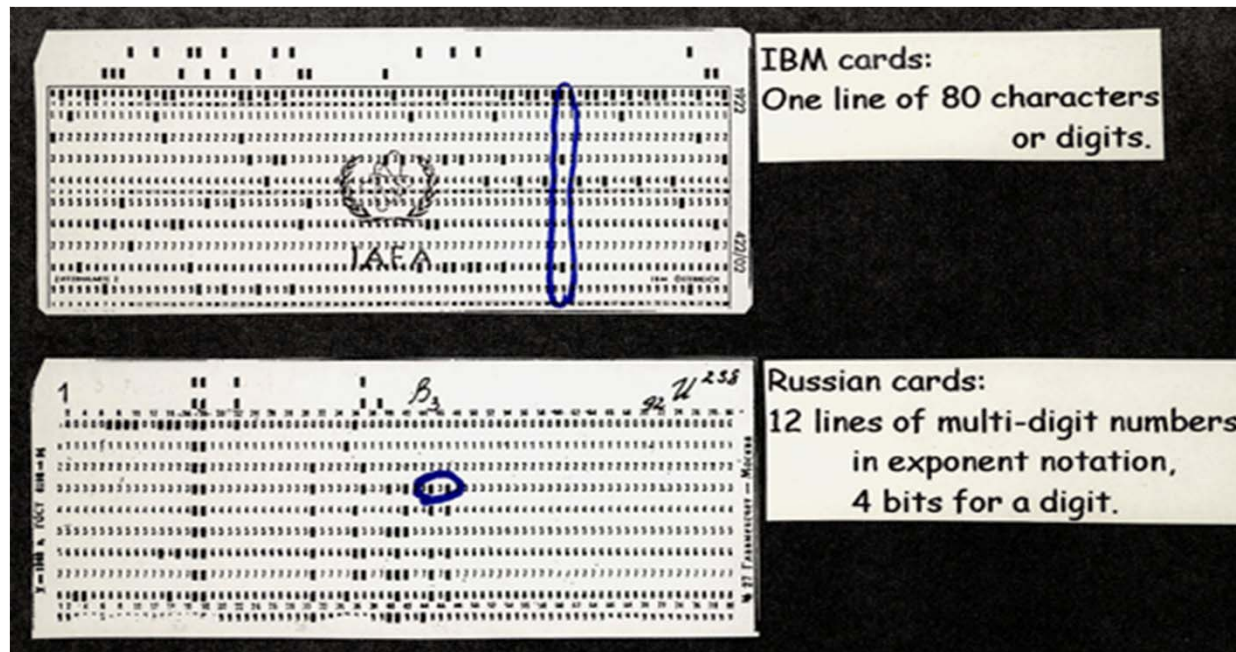


Headquarters in Vienna  
International Centre  
(1979- now)



# Data Exchange Between Western and Eastern Countries

- Cards received from western and eastern countries. Same size, but different format.
- Nuclear Data Unit developed a special code which translate data in one card format to the other one.



# Mission of IAEA Nuclear Data Section (IAEA NDS)

- The Nuclear Data Section (NDS) carries out the IAEA activities concerning development and dissemination of nuclear and atomic data for applications.
- Nuclear data for energy and non-energy application
  - Reactor (design, safety, spend fuel, decommissioning etc.)
  - Shielding
  - Dosimetry
  - Medical isotope production
  - Ion beam analysis
  - Safeguards
  - + Sciences (astrophysics etc.)

|       |   |       |       |       |       |       |       |       |       |
|-------|---|-------|-------|-------|-------|-------|-------|-------|-------|
| 185BI | 187PO   | 188PO | 189PO | 191AT | 190PO | 186BI | 185BI | 188BI | 185AU |
| 183HG | 181HG   | 182HG | 180AU | 179AU | 181TL | 182TL | 183TL | 186TL | 187TL |
| 178PT | Nuclear and Atomic Data<br>Providing Values for Science |       |       |       |       |       | 179PT | 179IR | 182PT |
| 177IR |   |       |       |       |       |       | 178IR | 179IR | 180IR |
| 176OS | 177OS   | 178OS | 179OS | 180OS | 181OS | 182OS | 175RE | 176RE | 177RE |
| 178RE | 179RE   | 180RE | 181RE | 182RE | 176W  | 177W  | 178W  | 179W  | 180W  |
| 172HF | 173HF   | 174HF | 175HF | 176HF | 177HF | 178HF | 179HF | 180HF | 181HF |
| 170YB | 171YB   | 172YB | 173YB | 174YB | 175YB | 170TM | 171TM | 172TM | 173TM |

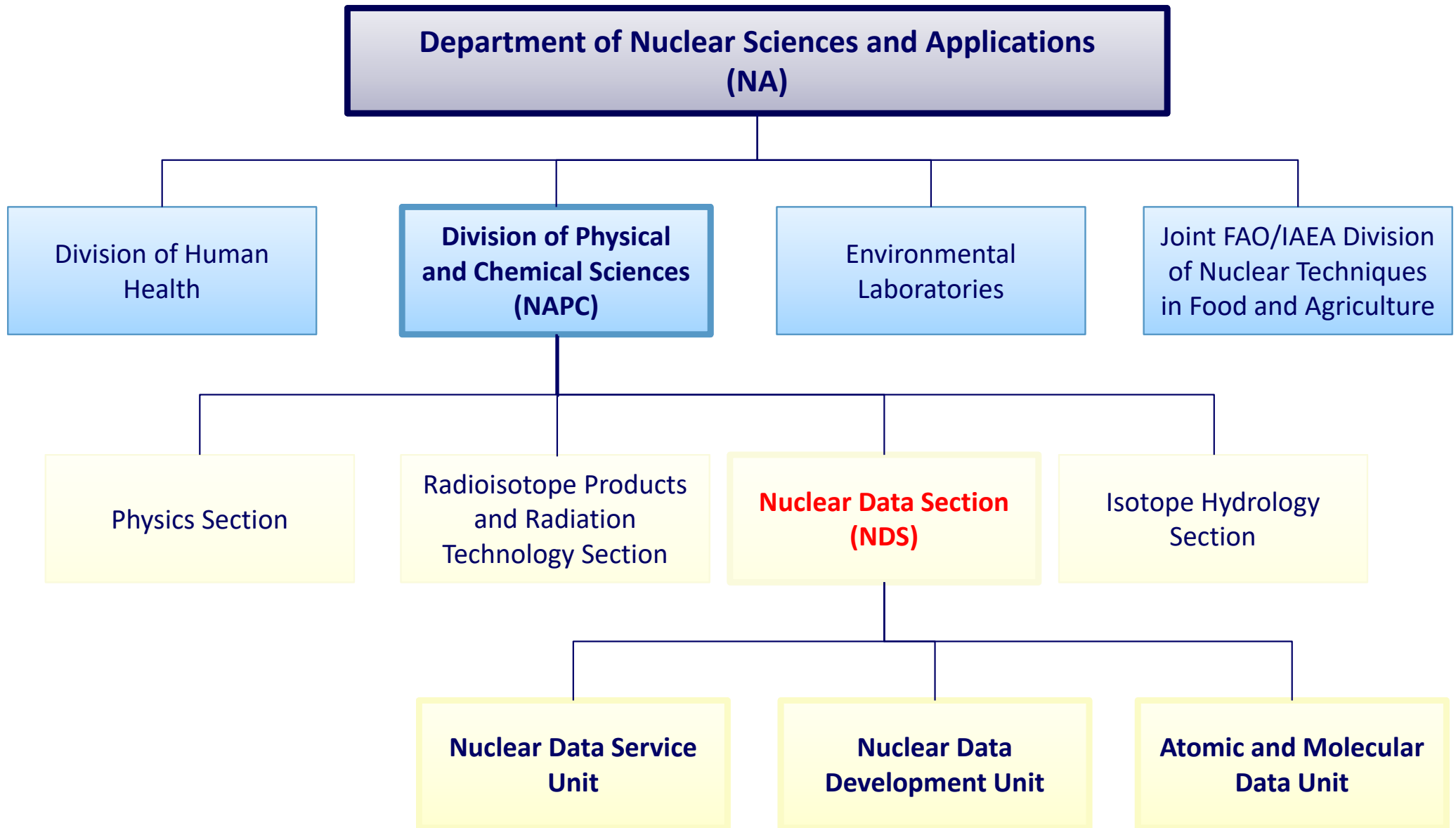


# Where is IAEA Nuclear Data Section?

Nuclear Data Section  
(NDS) on the 23rd floor



# Organization Chart







# NDS Staff List

Section Head: **Arjan Koning** 

Section Secretary & Team Assistant: **Charisse Monfero** 

| Nuclear Data Service Unit         |   |
|-----------------------------------|---|
| Unit Head:                        | <b>Jean-Christophe Sublet</b>  |
| Software Engineer:                | <b>(Vecant)</b>   |
| Nuclear Data Physicist:           | <b>Naohiko Otsuka</b>          |
| Associate Nuclear Data Physicist: | <b>Shin Okumura</b>          |
| Nuclear Data Services Assistant:  | <b>Lidija Vrapcenjak</b>     |
| Team Assistant:                   | <b>Szende Elias</b>          |

| Nuclear Data Development Unit |  |
|-------------------------------|--|
| Unit Head:                    | <b>Roberto Capote Noy</b>   |
| Nuclear Physicist:            | <b>Paraskevi Demetriou</b>  |
| Nuclear Physicist:            | <b>Georg Schnabel</b>       |
| Team Assistant:               | <b>Kira Nathani</b>       |

| Atomic & Molecular Data Unit     |   |
|----------------------------------|---|
| Unit Head:                       | <b>Christian Hill</b>    |
| Atomic Physicist:                | <b>Kalle Heinola</b>     |
| Nuclear Data Analyst/Programmer: | <b>Marco Verpelli</b>    |
| IT Systems Engineer:             | <b>Ludmila Marian</b>  |

12 professional staff and 4 supporting staff



# IAEA Nuclear Data Services

EXFOR (experimental reaction data)

ENDF (evaluated reaction data)

→ We will discuss them later.

IAEA.org | NDS Mission | About Us | Mirrors: India | China

Search  Go

NDS, June 2014

Coord. by NEA Data Bank, 2014 [page] [archive] [retrieve]  
IRDF - International Reactor Dosimetry and Fusion File v1.03 [page] [archive] [retrieve]  
CD/DVD-ROMs available for on-line downloading [page]  
Portable Empire-3.2.2 for Windows - nuclear reaction model code system for data evaluation [page] [download]

Main | All | Reaction Data | Structure & Decay | by Applications | Doc & Codes | NDS-Internal | Index | Events | Links | News

**EXFOR**  
Experimental nuclear reaction data

**LiveChart of Nuclides**  
Interactive Chart of Nuclides

**ENDF**  
Evaluated nuclear reaction libraries

**CINDA**  
Nuclear reaction bibliography

**NSR**  
Nuclear Science References

**Charged particle reference cross section**  
Beam monitor reactions

**IRDF**  
International Reactor Dosimetry and Fusion File

**Standards**

NSR (Bibliography)

Mirrors:  
Nuclear Data Services  
International Atomic Energy Agency  
Vienna, Austria

BARC, India  
Nuclear Data Services  
Bhabha Atomic Research Centre  
Mumbai, India

CNDC, China  
Nuclear Data Services  
China Institute of Atomic Energy  
Beijing

Partners:  
NND  
National Nuclear Data Center, Brookhaven, USA  
NEA

**LiveChart of Nuclides**

(evaluated structure and decay data)

<http://nds.iaea.org/> : primary server (Vienna)



# <http://www.nndc.bnl.gov/nsr/> NSR (Nuclear Science References)



National Nuclear Data Center



NNDC Databases: NuDat | NSR | XUNDL | ENSDF | MIRD | ENDF | CSISRS | Sigma

## Nuclear Science References (NSR)

NSR Reference Paper NIM A 640, 213 (2011)

Database version of January 14, 2015

The NSR database is a bibliography of nuclear physics articles, indexed according to content and spanning more than 100 years of research. Over 80 journals are checked on a regular basis for articles to be included. For more information, see the help page. The of the NSR Web

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

Quick Search

**Nuclide**   
*31Na or ca-38*

**Reaction**   
*n,g or (n,g) or (16O,16O)*

**Publication Year** from  to

**Reference Type**  All  Experiment  Theory

**Output Format**  HTML  BibTex  Text

Search

Reset





# NSR (cont.)

## Nuclear Science References (NSR)

NSR Reference Paper NIM A 640, 213 (2011)

Database version of December 18, 2014

Very easy to use!

Just provide

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

and search.

ysics articles, indexed according to content and spanning more than 1  
ided. For more information, see the [help page](#). The NSR database sche  
f the NSR Web Interface.

Number Search | Combine View | Recent References

**Author**  
*Brown or B.A.Brown*

**Nuclide**  
*<sup>31</sup>Na or ca-38*

**Reaction**  
*n,g or (n,g) or (16O,16O)*

**Publication Year** from  to

**Reference Type**  All  Experiment  Theory

**Output Format**  HTML  BibTex  Text



# NSR – Exercise 1

## Question

Search articles where  
“Balasubramaniam”  
is an author.

## Nuclear Science References (NSR)

NSR Reference Paper NIM A 640, 213 (2011)

Database version of December 18, 2014

ysics articles, indexed according to content and spanning more than :  
ided. For more information, see the [help page](#). The NSR database sche  
f the NSR Web Interface.

Number Search | Combine View | Recent References

---

**Author**   
*Brown or B.A.Brown*

**Nuclide**   
 *$^{31}\text{Na}$  or ca-38*

**Reaction**   
*n,g or (n,g) or (16O,16O)*

**Publication Year** from  to

**Reference Type**  All  Experiment  Theory

**Output Format**  HTML  BibTex  Text



# NSR – Exercise 2

## Nuclear Science References (NSR)

NSR Reference Paper NIM A 640, 213 (2011)

Database version of December 18, 2014

### Question

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

ysics articles, indexed according to content and spanning more than :  
ided. For more information, see the [help page](#). The NSR database sche  
f the NSR Web Interface.

Number Search | Combine View | Recent References

**Author**  
*Brown or B.A.Brown*

**Nuclide**  
*31Na or ca-38*

**Reaction**  
*n,g or (n,g) or (16O,16O)*

**Publication Year** from  to

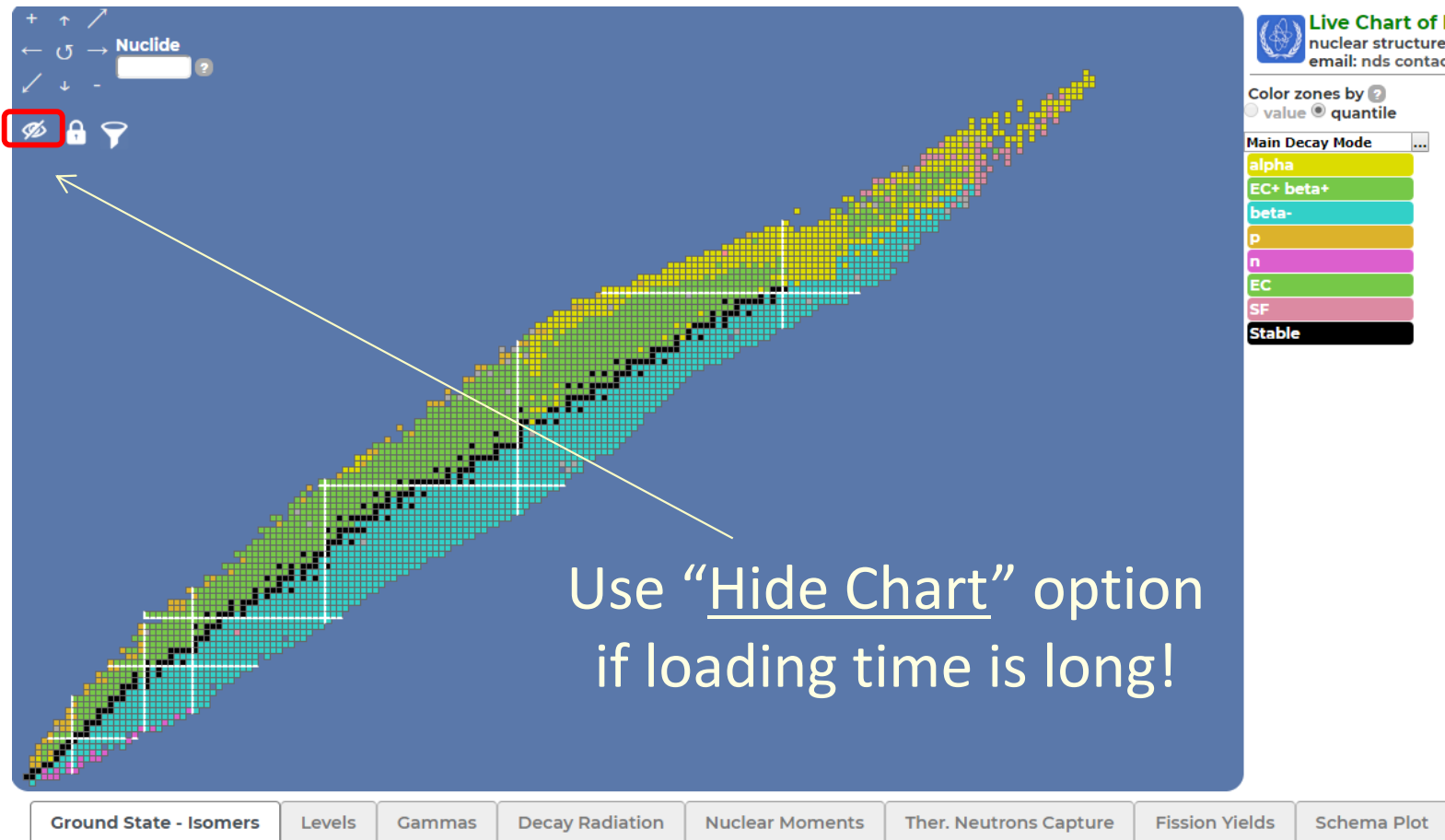
**Reference Type**  All  Experiment  Theory

**Output Format**  HTML  BibTex  Text



# LiveChart of Nuclides

<http://nds.iaea.org/livechart/>



# LiveChart of Nuclides (cont.)

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

The screenshot displays the LiveChart of Nuclides interface. At the top, there are links for 'List of updates' (Mar 2018 to Jan 2019), 'Mass chains' ( $\beta$  and ec decays plotting), and 'Neutron Cross Sections' (Resonance Integrals). Below these is the 'Live Chart of Nuclides' title and the subtitle 'nuclear structure and decay data'. A search bar labeled 'Go to Nuclide:' is highlighted with a red circle, and a 'Show Chart' button is next to it. Below the search bar is a row of tabs: 'Ground State - Isomers', 'Levels', 'Gammas', 'Decay Radiation', 'Nuclear Moments', 'Ther. Neutrons Capture', 'Fission Yields', and 'Schema Plot'. Below the tabs are several promotional boxes: 'New in Livechart' (Sep 2019 Thermal n Cross Section update), 'Isotope Browser for mobile' (with icons for iOS, Android, and Amazon apps), '3D Plotting with zoom, rotation, and filter', 'Data update' (ENSDF snapshot January 2019), 'Search & Filter' (query panel on structure and decay), and 'Decay Portal' (compare different evaluations). A blue arrow points from the 'Show Chart' button to the 'Ground State - Isomers' tab.

Type a nuclide symbol  
(e.g.,  $^{135}\text{Xe}$ )

# LiveChart of Nuclides – $^{135}\text{Xe}$

## Ground State - Isomers tab

Go to Nuclide:  [Show Chart](#)

**Ground State - Isomers**

Levels

Gammas

Decay Radiation

Nuclear Moments

Ther.

Comments  · **Click** on a column header to open the guide · **Uncertainty** for numeric values refers to the last digit  
**Sources**

· **Evaluation:** BALRAJ SINGH, ALEXANDER A. RODIONOV and YURI L. KHAZOV **Publication cut-off:** 22-Jan-2008 **ENSDF**

Ground state

| Nuclide                 | Energy [keV] | $J^\pi$ | $T_{1/2}$ Abund. [mole fract.] | $T_{1/2}$ [s] | Decay Modes BR [%]           | Isospin | $\mu$ [ $\mu_N$ ] | Q [barn]  | R [fm] | $Q_{\beta^-}$ [keV] |
|-------------------------|--------------|---------|--------------------------------|---------------|------------------------------|---------|-------------------|-----------|--------|---------------------|
| $^{135}_{54}\text{Xe}$  | 0.0          | 3/2+    | 9.14 h 2                       | 3.29E4        | $\beta^-$ 100                |         | +0.9032 7         | +0.214 7  |        | 1168 .              |
| $^{135m}_{54}\text{Xe}$ | 526.551 13   | 11/2-   | 15.29 min 5                    | 9.17E2        | IT > 99.4<br>$\beta^-$ < 0.6 |         | -1.1036 14        | +0.618 27 |        |                     |

Metastable state



# LiveChart of Nuclides - $^{135}\text{Xe}$ (cont.)

## Levels tab

Go to Nuclide:  [Show Chart](#)

[Ground State - Isomers](#)
[Levels](#)
[Gammas](#)
[Decay Radiation](#)
[Nuclear Moments](#)
[Ther. Neu](#)

38 rows retrieved

Comments  · **Click** on a column header to open the guide · **Uncertainty** for numeric values refers to the last digit

[Definitions & Sources](#)

[CSV](#) Evaluation: BALRAJ SINGH, ALEXANDER A. RODIONOV and YURI L. KHAZOV Publication cut-off: 22-Jan-2008 ENS

| Nuclide                     | $E_x$ [keV] | $J^\pi$ order | Band | $T_{1/2}$   | $T_{1/2}$ [s] | Decay modes<br>BR [%]        | Isospin | $\mu$<br>[ $\mu_N$ ] | $Q$<br>[b] | Adc |
|-----------------------------|-------------|---------------|------|-------------|---------------|------------------------------|---------|----------------------|------------|-----|
| $^{135}_{54}\text{Xe}_{81}$ | 0.0         | 3/2+          |      | 9.14 h 2    | 3.29E4        | $\beta^-$ 100                |         | +0.9032 7            | +0.214 7   |     |
| $^{135}_{54}\text{Xe}_{81}$ | 288.455 15  | 1/2+          |      |             |               |                              |         |                      |            |     |
| $^{135}_{54}\text{Xe}_{81}$ | 526.551 13  | 11/2-         |      | 15.29 min 5 | 9.17E2        | IT > 99.4<br>$\beta^-$ < 0.6 |         | -1.1036 14           | +0.618 27  |     |
| $^{135}_{54}\text{Xe}_{81}$ | 1131.512 11 | 7/2+          |      |             |               |                              |         |                      |            |     |
| $^{135}_{54}\text{Xe}_{81}$ | 1260.416 13 | 5/2+          |      |             |               |                              |         |                      |            |     |
| $^{135}_{54}\text{Xe}_{81}$ | 1448.36 3   | (3/2+)        |      |             |               |                              |         |                      |            |     |

\_\_\_\_\_ 7/2+  
 \_\_\_\_\_ 11/2+  
 \_\_\_\_\_ 1/2+  
 \_\_\_\_\_ 3/2+  
 $^{135}\text{Xe}$



# LiveChart of Nuclides - $^{135}\text{Xe}$ (cont.)

## Decay Radiation tab

Go to Nuclide:  [Show Chart](#)

Ground State - Isomers    Levels    Gammas    **Decay Radiation**    Nuclear Moments    The

100%  $\beta^-$  - 9.14 h

•1  $^{135}_{54}\text{Xe} \rightarrow ^{135}_{55}\text{Cs}$

99.4% IT - 15.29 min

•2  $^{135m}_{54}\text{Xe} \rightarrow ^{135}_{54}\text{Xe}$

0.6%  $\beta^-$  - 15.29 min

•3  $^{135m}_{54}\text{Xe} \rightarrow ^{135}_{55}\text{Cs}$

Comments  - Click on a column header to open the guide - Uncertainty for numeric values refers to the Data from: ENSDF apart Q from AME2016 - Definitions & Sources

•1 Evaluation: BALRAJ SINGH, ALEXANDER A. RODIONOV and YURI L. KHAZOV Publication cut-off: 22-Jan-2008 E

| Parent                 | $T_{1/2}$ | $E_x$ [keV] | J $\pi$ order | Decay             | Q <sub>decay</sub><br>note on Q value | Daughter               | Comments | Total energy by rad |              |
|------------------------|-----------|-------------|---------------|-------------------|---------------------------------------|------------------------|----------|---------------------|--------------|
|                        |           |             |               |                   |                                       |                        |          | Alpha               | Beta         |
| $^{135}_{54}\text{Xe}$ | 9.14 h 2  | 0.0         | 3/2+          | $\beta^-$ - 100 % | 1168 4                                | $^{135}_{55}\text{Cs}$ |          | 0.000               | 0.000 304.71 |

see the ENSDF source

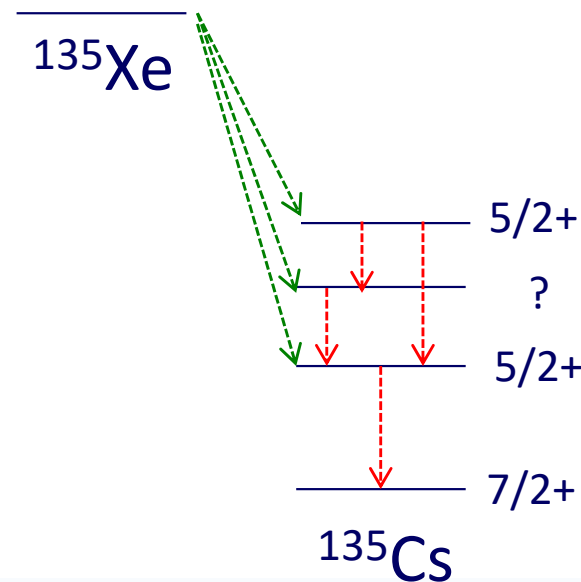
Note: Q-value used in ENSDF to determine displayed decay data is: 1165 4 keV - see note on Q value

**Beta -** [CSV](#)

| $\langle E_{\beta} \rangle$<br>[keV] | $I_{\beta}$ -(abs)<br>[%] | Daughter level<br>[keV] | J $\pi$ | $E_{\beta, \max}$<br>[keV] | logft  | Transition type | Comments |
|--------------------------------------|---------------------------|-------------------------|---------|----------------------------|--------|-----------------|----------|
| 26.9 11                              | 0.123 6                   | 1062.420 14             |         | (103)                      | 5.71 6 |                 |          |
| 50.0 12                              | 0.075 5                   | 981.315 22              |         | (184)                      | 6.71 5 |                 |          |
| 173.3 15                             | 3.11 14                   | 608.186 14              | 5/2+    | (557)                      | 6.67 3 | allowed         |          |
| 248.1 16                             | 0.59 3                    | 407.989 13              |         | (757)                      | 7.86 3 |                 |          |
| 310.2 16                             | <b>96 4</b>               | 249.793 12              | 5/2+    | 910 10                     | 5.94 2 | allowed         |          |

**Gamma** [CSV](#)

| $E_{\gamma}$<br>[keV] | $I_{\gamma}$ -(abs)<br>[%] | Initial level<br>[keV] | J $\pi$ | Final level<br>[keV] | J $\pi$ | Mult.   | $\delta$ | $\alpha_{\tau}$ | Comments |
|-----------------------|----------------------------|------------------------|---------|----------------------|---------|---------|----------|-----------------|----------|
| 158.197 18            | 0.289 14                   | 407.989 13             |         | 249.793              | 5/2+    |         |          |                 |          |
| 200.19 10             | 0.012 5                    | 608.186 14             | 5/2+    | 407.989              |         |         |          |                 |          |
| 249.794 15            | <b>90 3</b>                | 249.793 12             | 5/2+    | 0.0                  | 7/2+    | M1(+E2) | < 1.0    | 0.0737 20       |          |
| 358.39 3              | 0.220 11                   | 608.186 14             | 5/2+    | 249.793              | 5/2+    | M1,E2   |          | 0.0265 17       |          |



$\beta$ -decay

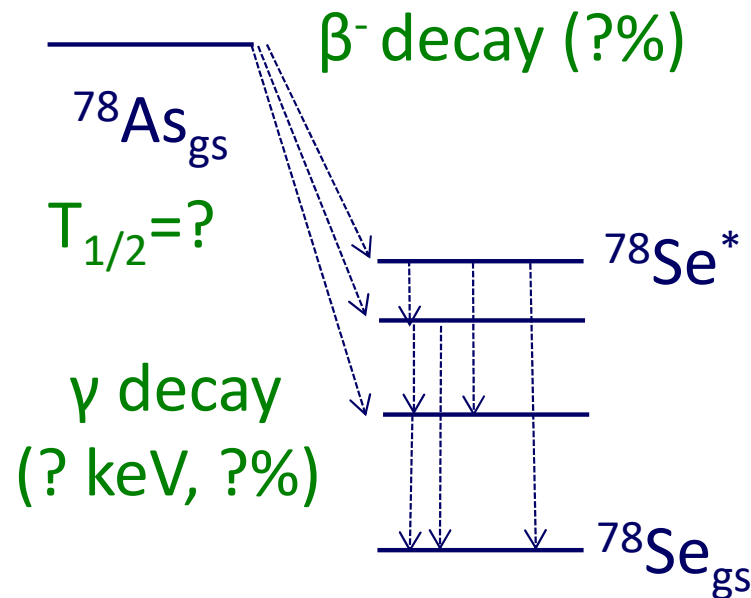
$\gamma$ -decay





# LiveChart of Nuclides - Exercise

One determined the  $^{78}\text{Se}(n,p)^{78}\text{As}$  cross section by detection of  $\gamma$  from  $^{78}\text{As} - \beta^- \text{ decay} \rightarrow ^{78}\text{Se}^* - \gamma \text{ decay} \rightarrow ^{78}\text{Se}_{\text{gs}}$ .

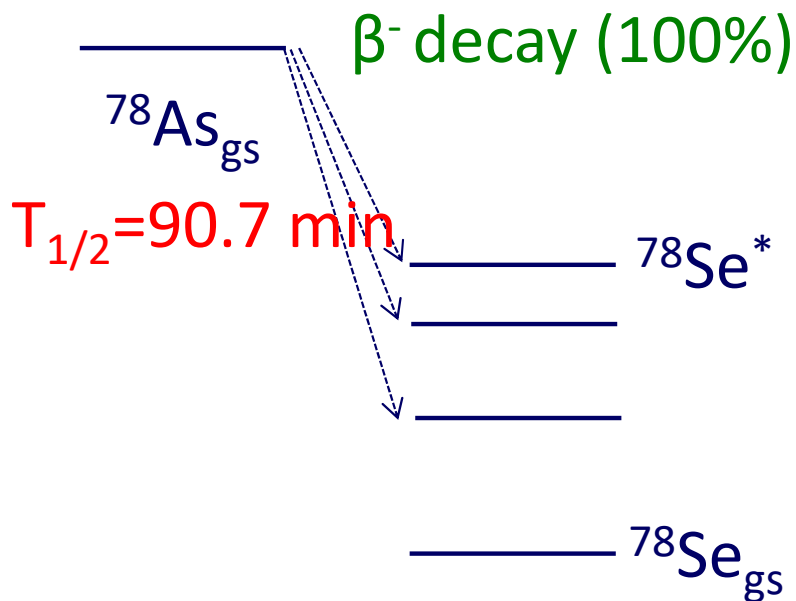


## Questions:

1. Half-life of  $^{78}\text{As}$
2. Branching ratio of  $^{78}\text{As} \beta^- \text{ decay}$
3. Energy of strongest decay  $\gamma$  radiation and its intensity



# LiveChart of Nuclides – Exercise (cont)



## Questions:

1. Half-life of  $^{78}\text{As}$
2. Branching ratio of  $^{78}\text{As}$   $\beta^-$  decay
3. Energy of strongest decay  $\gamma$  radiation and its intensity

Go to Nuclide:  [Show Chart](#)

**Ground State - Isomers** | Levels | Gammas | Decay Radiation | Nuclear

Comments  · **Click** on a column header to open the guide · **Uncertainty** for numbers

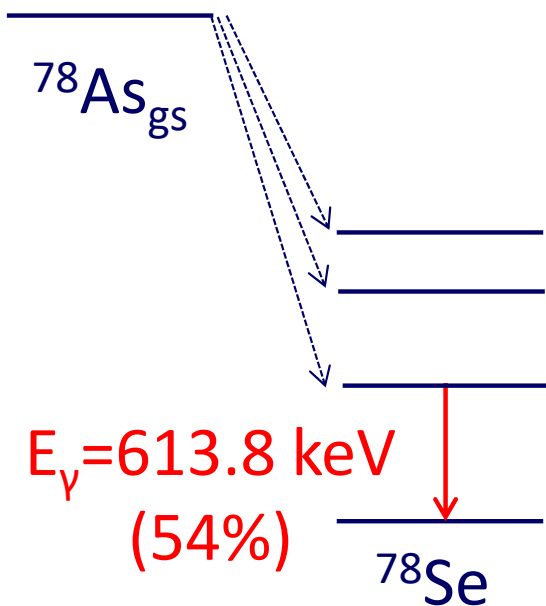
**Sources**

· Evaluation: AMEENAH B. FADHAN, BALRAJ SINGH Publication cut-off: 30-Jun-2009 ENSDF i

| Nuclide                    | Energy [keV] | $J^\pi$ | $T_{1/2}$ Abund. [mole fract.] | $T_{1/2}$ [s] | Decay Modes BR [%] | Isospin | $\mu$ [ $\mu_N$ ] | $Q$ [bar] |
|----------------------------|--------------|---------|--------------------------------|---------------|--------------------|---------|-------------------|-----------|
| $^{78}_{33}\text{As}_{45}$ | 0.0          | 2-      | 90.7 min 2                     | 5.44E3        | $\beta^-$ 100      |         |                   |           |



# LiveChart of Nuclides – Exercise (cont)



## Questions:

1. Half-life of  $^{78}\text{As}$
2. Branching ratio of  $^{78}\text{As}$   $\beta^{-}$  decay
3. Energy of strongest decay  $\gamma$  radiation and its intensity

Go to Nuclide:  [Show Chart](#)

Ground State - Isomers   Levels   Gammas   **Decay Radiation**   Nuclear Moments

Comments  · Click on a column header to open the guide · Uncertainty for numeric values  
 Data from: ENSDF apart Q from **AME2016** · [Definitions & Sources](#)

**Gamma** [CSV](#)

| $E_{\gamma}$<br>[keV] | $\gamma_{\text{int}}$ (abs)<br>[%] | Initial level<br>[keV] | $J^{\pi}$ | Final level<br>[keV] | $J^{\pi}$ | Mult. | $\delta$ | $\alpha_{\text{T}}$ | Comments |
|-----------------------|------------------------------------|------------------------|-----------|----------------------|-----------|-------|----------|---------------------|----------|
| 156.6                 | 0.092                              | 2838.58                | (2+)      | 2682.09              | 4+        |       |          |                     |          |
| 174.2                 | 0.18                               | 2682.09                | 4+        | 2507.72              | 3-        |       |          |                     |          |
| 351.1                 | 0.162                              | 1854.00                | 3+        | 1502.64              | 4+        |       |          |                     |          |
| 354.3                 | 1.9                                | 2682.09                | 4+        | 2327.34              | 2+        |       |          |                     |          |
| 391.0                 | 0.124                              |                        |           |                      |           |       |          |                     |          |
| 449.8                 | 0.08                               | 1758.91                | 0+        | 1308.66              | 2+        |       |          |                     |          |
| 462.2                 | 0.59                               | 3144.52                | 3-        | 2682.09              | 4+        |       |          |                     |          |
| 468.8                 | 0.097                              |                        |           |                      |           |       |          |                     |          |
| 497.0                 | 0.18                               | 1995.78                | 2+        | 1498.76              | 0+        |       |          |                     |          |
| 503.7                 | 0.42                               | 2838.58                | (2+)      | 2334.87              | 0+        |       |          |                     |          |
| 545.3                 | 3.0                                | 1854.00                | 3+        | 1308.66              | 2+        |       |          |                     |          |
| 551.8                 | 0.17                               |                        |           |                      |           |       |          |                     |          |
| 613.8                 | <b>54.6</b>                        | 613.84                 | 2+        | 0.0                  | 0+        |       |          |                     |          |
| 673.2                 | 0.21                               | 3144.52                | 3-        | 2507.72              | 3-        |       |          |                     |          |

ENSDF insertion: 2

| Comments | Total |
|----------|-------|
|          | Alp   |
|          | 0.00  |



# 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  $\gamma$  intensity)

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

We extracted these data from LiveChart.

TABLE I. The decay data of the radioisotopes produced

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



## 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)**.



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