



International Atomic Energy Agency

The 8th DAE-BRNS Theme Meeting on

EXFOR Compilation of Nuclear Data

Department of Physics, The M.S. University, Vadodara, India

12–16 November 2019

Introduction to IAEA Nuclear Data Services

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Nuclear Data Section

Department of Nuclear Sciences and Applications



सत्यं शिवं सुन्दरम्



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.

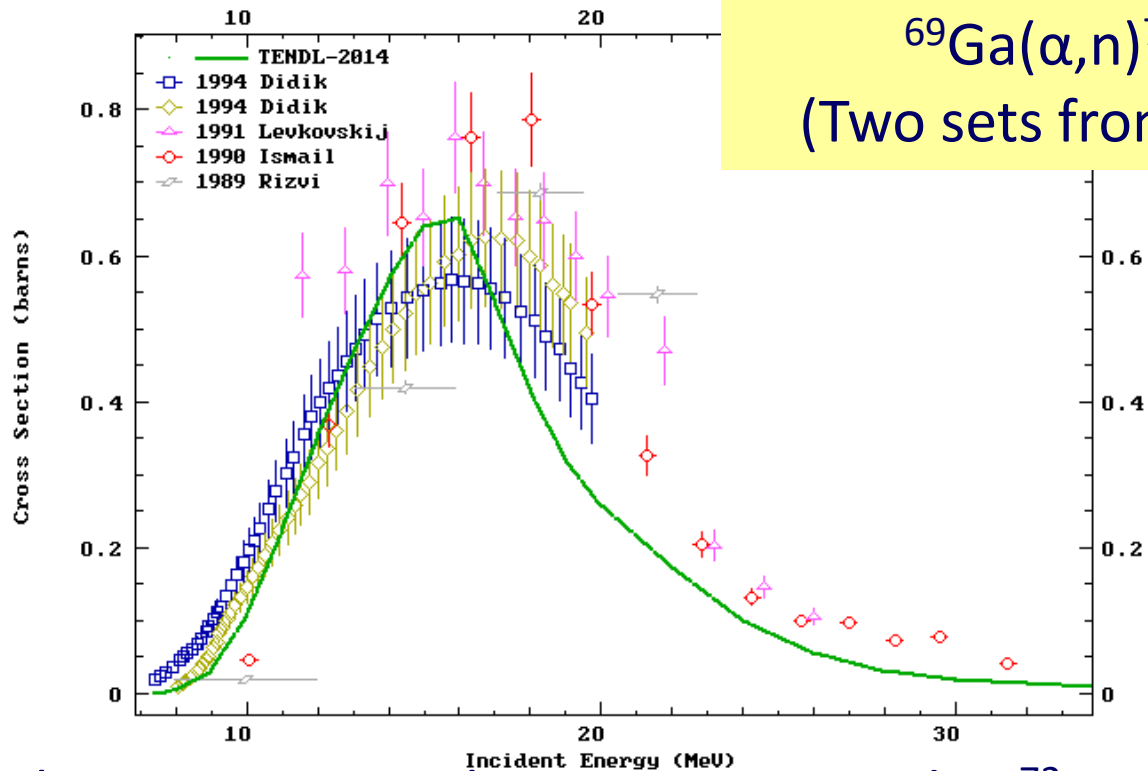
However this improved rice absorbs more As ☹️

→ Needs of As RI tracer.



Nuclear Data for ^{72}As (26 hrs) Tracer Production

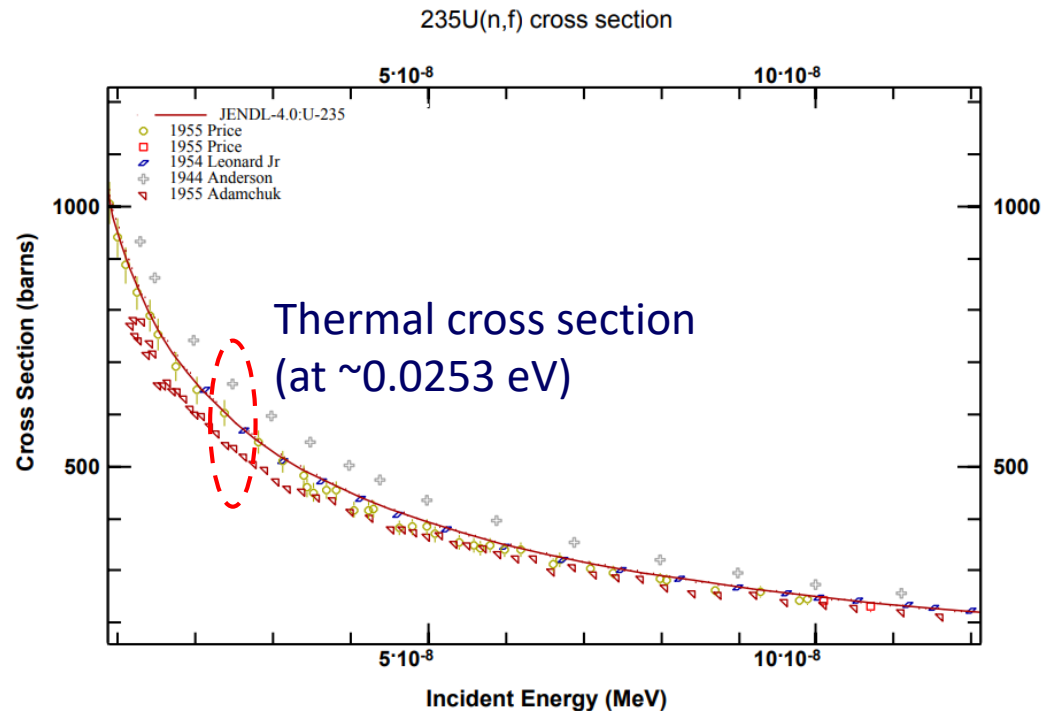
31-GA-69(A,N)33-AS-72,,SIG



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

Nuclear Data in the 1950s – “Classified Information”

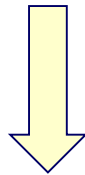
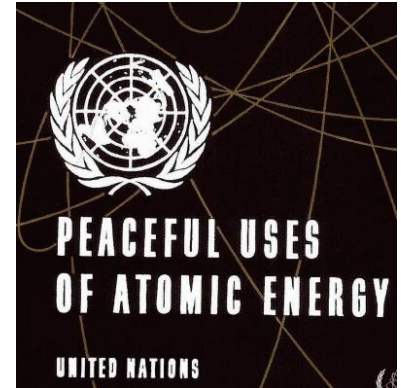
Nuclear data information was classified in the 1950s. Even $^{235}\text{U}(n_{\text{th}},f)$ cross section was not an well stablished constant.



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)



Stephansdom

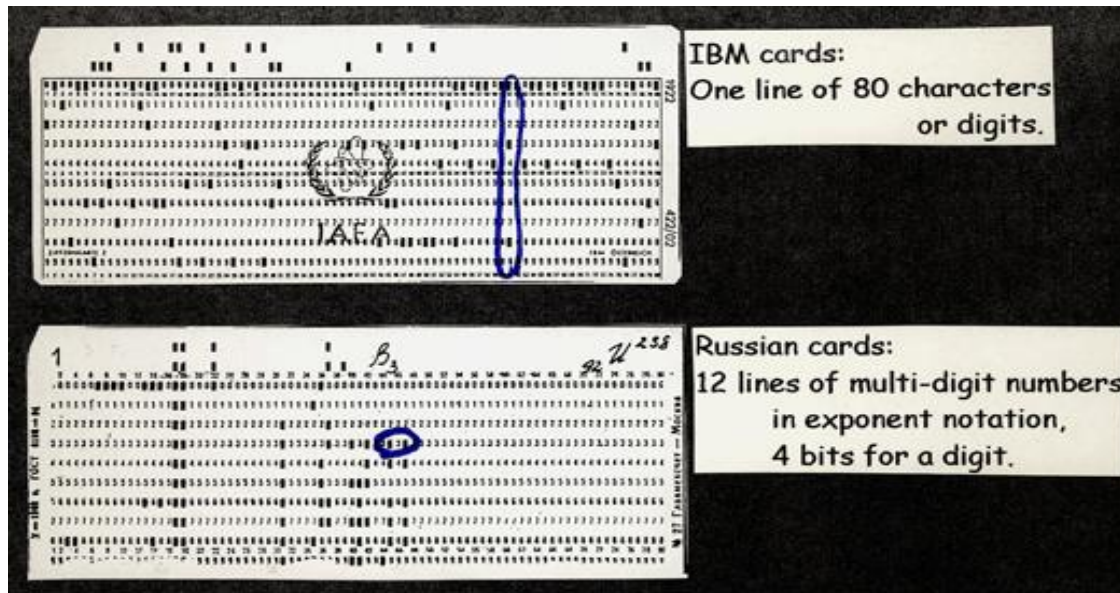


Headquarters in Vienna
International Centre
(1979- now)



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 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

Department of Nuclear Sciences and Applications
(NA)

Division of Human
Health

Division of Physical
and Chemical Sciences
(NAPC)

Environmental
Laboratories

Joint FAO/IAEA Division
of Nuclear Techniques
in Food and Agriculture

Physics Section

Radioisotope Products
and Radiation
Technology Section

**Nuclear Data Section
(NDS)**

Isotope Hydrology
Section

Nuclear Data Service
Unit

Nuclear Data
Development Unit

Atomic and Molecular
Data Unit



NDS Staff List


Section Head: **Arjan Koning** 

Section Secretary & Team Assistant: **Rosalinda Rangel Alvarez** 


Nuclear Data Service Unit

Unit Head:

Jean-Christophe Sublet 

Software Engineer:
Viktor Zerkin 

Nuclear Data Physicist:
Naohiko Otsuka 

Associate Nuclear Data Physicist:
Shin Okumura 


Nuclear Data Services Assistant:
Lidija Vrapcenjak 

Team Assistant:
(Vacant) 

Nuclear Data Development Unit

Unit Head:

Roberto Capote Noy 

Nuclear Physicist:
Andrej Trkov 

Nuclear Physicist:
(Vacant)

Team Assistant:
Kira Nathani 


Atomic & Molecular Data Unit


Unit Head:

Christian Hill 

Atomic Physicist:
Kalle Heinola 

Nuclear Data Analyst/Programmer:
Marco Verpelli 

IT Systems Engineer:
Ludmila Marian 

Information System Assistant:
Mark O'Connell (1/4) 

12 professional staff and 4 supporting staff



IAEA Nuclear Data Services

EXFOR (experimental reaction data)

ENDF (evaluated reaction data)

→ We will discuss them later.

CD/DVD with documentation, data, codes, etc.

Quick Links
ADS-Lib
Atomic Mass Data Centre
CINDA
Charged particle reference cross section
DROSG-2000
EMPIRE-3.2

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]

EXFOR
Experimental nuclear reaction data

ENDF
Evaluated nuclear reaction libraries

LiveChart of Nuclides
Interactive Chart of Nuclides

ENSDF
evaluated nuclear structure and decay data (+XUNDL) **

CINDA
Nuclear reaction bibliography

NSR
Nuclear Science References *

Charged particle reference cross section
Beam monitor reactions

IRDF
International Reactor Dosimetry and Fusion File

Standards

*Database at the IAEA, Vienna **Database at the US NNDC

LiveChart of Nuclides

(evaluated structure and decay data)

NSR (Bibliography)

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

NSR (Nuclear Science References)

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

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



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 100 years. For more information, see the [help page](#). The NSR database scheme is available in 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

NSR – Exercise 1

Nuclear Science References (NSR)

NSR Reference Paper NIM A 640, 213 (2011)

Database version of December 18, 2014

Question

Search articles where
“Nayak” is an author.

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
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

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 $^{78}\text{Se}(n,p)^{78}\text{As}$.

Physics articles, indexed according to content and spanning more than 100 years. For more information, see the [help page](#). The NSR database schema is available in 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

NSR – Exercise 2 (cont)

Not all articles report the $^{78}\text{Se}(n,p)$ 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 $^{75m,75g}\text{Ge}$ in (n, p) , (n, α) , and $(n, 2n)$ Reactions from 6 to 15 MeV

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

doi: [10.1103/PhysRevC.52.2546](https://doi.org/10.1103/PhysRevC.52.2546)

Data from this article have been entered in the **EXFOR** database. For more information, access X4 [dataset22291](#).

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

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

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

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



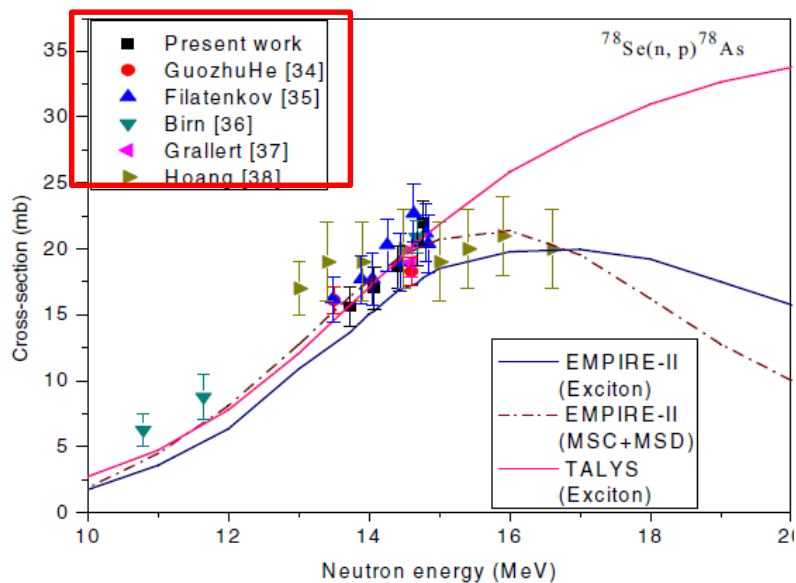
NSR – Exercise 2 (cont)

Compare NSR output for

“Nuclide = ^{78}Se 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?



[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).

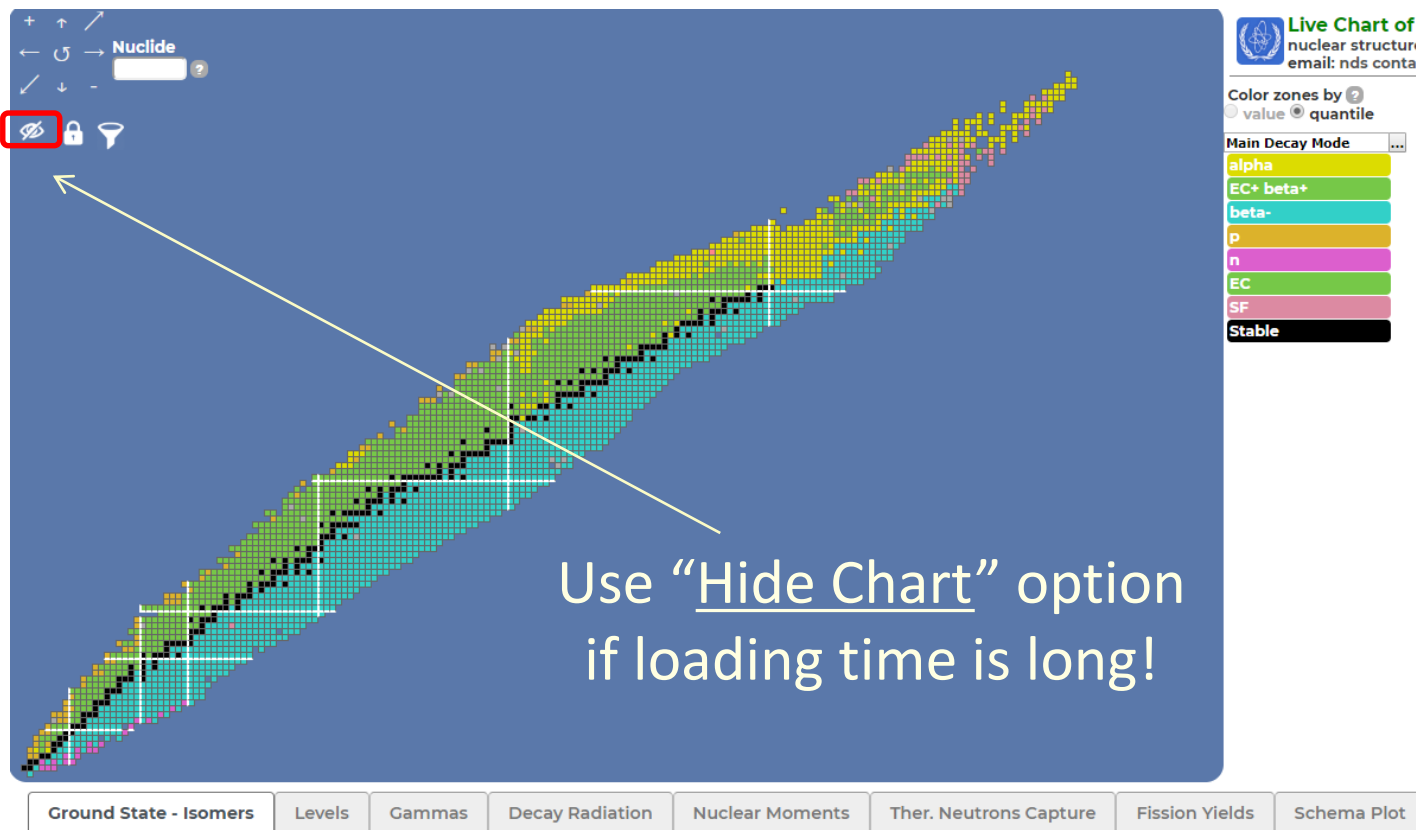
Not in NSR

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

in NSR

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

LiveChart of Nuclides



<http://www-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" (β 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 horizontal menu with tabs: "Ground State - Isomers", "Levels", "Gammas", "Decay Radiation", "Nuclear Moments", "Ther. Neutrons Capture", "Fission Yields", and "Schema Plot". At the bottom, there 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 text "Type a nuclide symbol (e.g., 135Xe)" to the search input field.

Type a nuclide symbol
(e.g., 135Xe)

LiveChart of Nuclides – ^{135}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**

Nuclide	Energy [keV]	J^π	$T_{1/2}$ Abund. [mole fract.]	$T_{1/2}$ [s]	Decay Modes BR [%]	Isospin	μ [μ_N]	Q [barn]	R [fm]	Q_{β^-} [keV]
$^{135}_{54}\text{Xe}$	0.0	3/2+	9.14 h 2	3.29E4	β^- 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 β^- < 0.6		-1.1036 14	+0.618 27		

Ground state

Metastable state

LiveChart of Nuclides - ^{135}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^π order	Band	$T_{1/2}$	$T_{1/2}$ [s]	Decay modes BR [%]	Isospin	μ [μ_N]	Q [b]	Adc
$^{135}_{54}\text{Xe}_{81}$	0.0	3/2+		9.14 h 2	3.29E4	β^- 100		+0.9032 7	+0.214 7	7/2+
$^{135}_{54}\text{Xe}_{81}$	288.455 15	1/2+								11/2+
$^{135}_{54}\text{Xe}_{81}$	526.551 13	11/2-		15.29 min 5	9.17E2	IT > 99.4 β^- < 0.6		-1.1036 14	+0.618 27	1/2+
$^{135}_{54}\text{Xe}_{81}$	1131.512 11	7/2+								3/2+
$^{135}_{54}\text{Xe}_{81}$	1260.416 13	5/2+								^{135}Xe
$^{135}_{54}\text{Xe}_{81}$	1448.36 3	(3/2+)								

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

Decay Radiation tab

Go to Nuclide: [Show Chart](#)

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

100% β - 9.14 h

$^{135}_{54}\text{Xe} \rightarrow ^{135}_{55}\text{Cs}_{80}$

99.4% IT 15.29 min

$^{135m}_{54}\text{Xe} \rightarrow ^{135}_{54}\text{Xe}_{81}$

0.6% β - 15.29 min

$^{135m}_{54}\text{Xe} \rightarrow ^{135}_{55}\text{Cs}_{80}$

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 π order	Decay	Q decay note on Q value	Daughter	Comments	Total energy by radiation	
								Alpha	Beta
$^{135}_{54}\text{Xe}$	9.14 h 2	0.0	3/2+	β - 100 %	1168 4	$^{135}_{55}\text{Cs}_{80}$		0.000 0.000	304.71

see the ENSDF source

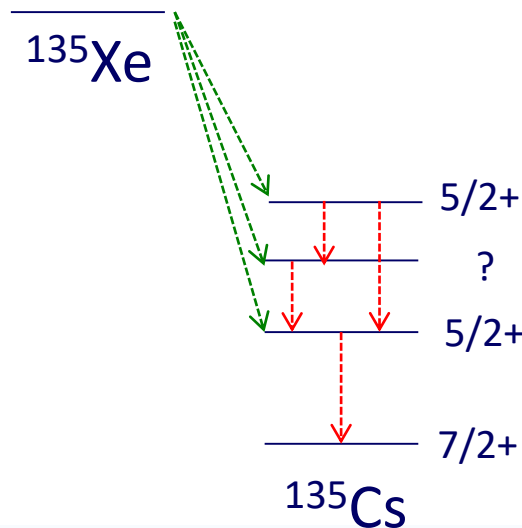
Note: Q-value used in ENSDF to determine displayed decay data is: 1165 4 keV - see [note on Q value](#)

Beta - [CSV](#)

$\langle E_\beta \rangle$ [keV]	I_β .(abs) [%]	Daughter level [keV]	J π	$E_{\beta-,max}$ [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	96 4	249.793 12	5/2+	910 10	5.94 2	allowed	

Gamma [CSV](#)

E_γ [keV]	I_γ .(abs) [%]	Initial level [keV]	J π	Final level [keV]	J π	Mult.	δ	α_τ	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	90 3	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	



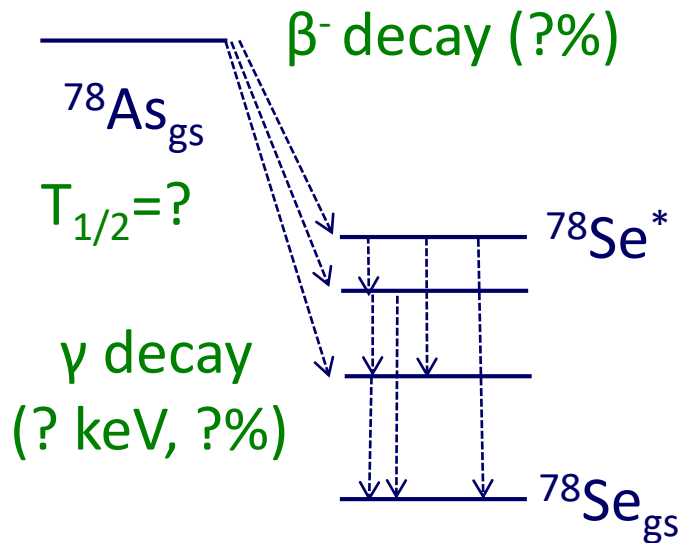
β -decay

γ -decay



LiveChart of Nuclides - Exercise

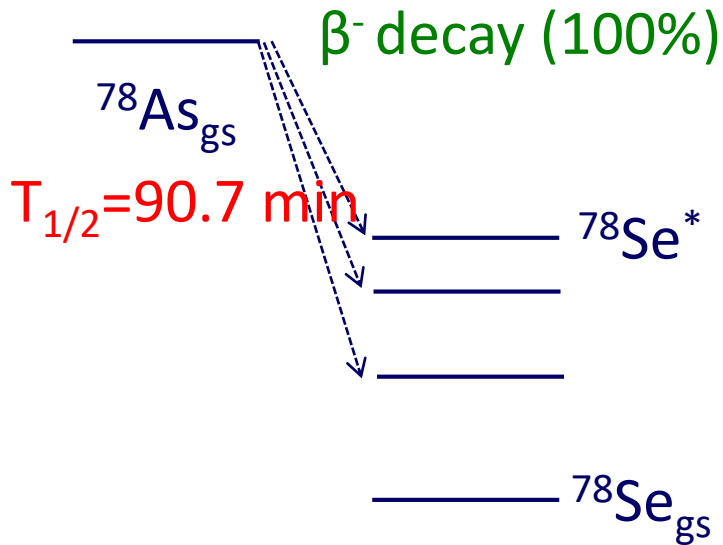
One determined the $^{78}\text{Se}(n,p)^{78}\text{As}$ cross section by detection of γ from $^{78}\text{As} - \beta^- \text{ decay} \rightarrow ^{78}\text{Se}^* - \gamma \text{ decay} \rightarrow ^{78}\text{Se}_{\text{gs}}$.



Questions:

1. Half-life of ^{78}As
2. Branching ratio of $^{78}\text{As} \beta^- \text{ decay}$
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

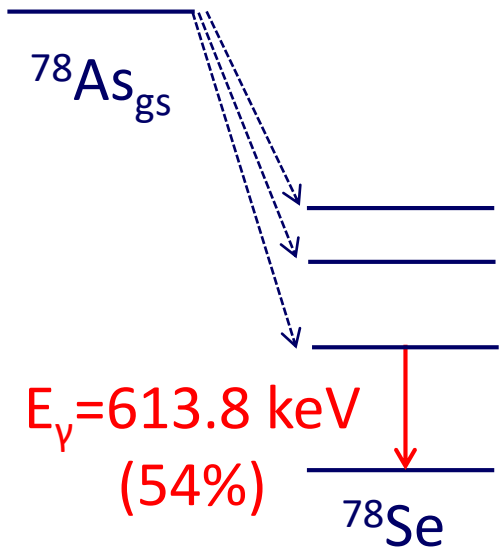
Go to Nuclide:

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

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

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

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

Go to Nuclide:

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

Gamma		Initial level		Final level		Mult.		Comments	
E_{γ} [keV]	$I_{\gamma}(\text{abs})$ [%]	[keV]	J^{π}	[keV]	J^{π}	δ	α_{T}		
156.6	0.092	2838.58	9 (2+)	2682.09	4+				
174.2	0.18	2682.09	9 4+	2507.72	3-				
351.1	0.162	1854.00	9 3+	1502.64	4+				
354.3	1.9	2682.09	9 4+	2327.34	2+				
391.0	0.124								
449.8	0.08	1758.91	11 0+	1308.66	2+				
462.2	0.59	3144.52	13 3-	2682.09	4+				
468.8	0.097								
497.0	0.18	1995.78	10 2+	1498.76	0+				
503.7	0.42	2838.58	9 (2+)	2334.87	0+				
545.3	3.0	1854.00	9 3+	1308.66	2+				
551.8	0.17								
613.8	54.6	613.84	7 2+	0.0	0+				

ENSDF insertion: 2

Total	
Comments	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 γ intensity)

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

We extracted these data from LiveChart.

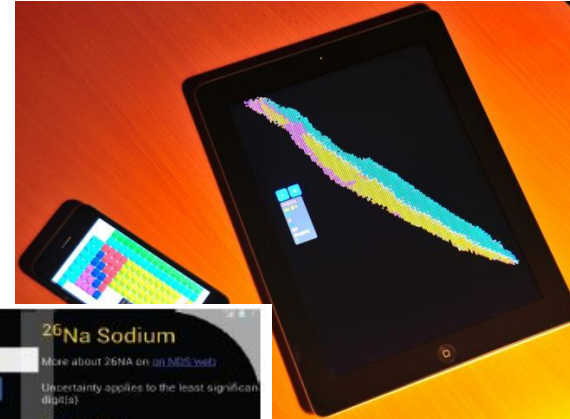
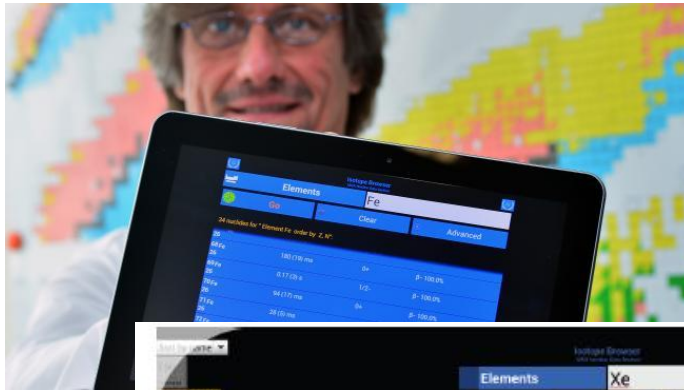
TABLE I. The decay data of the radioisotopes produced

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

