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

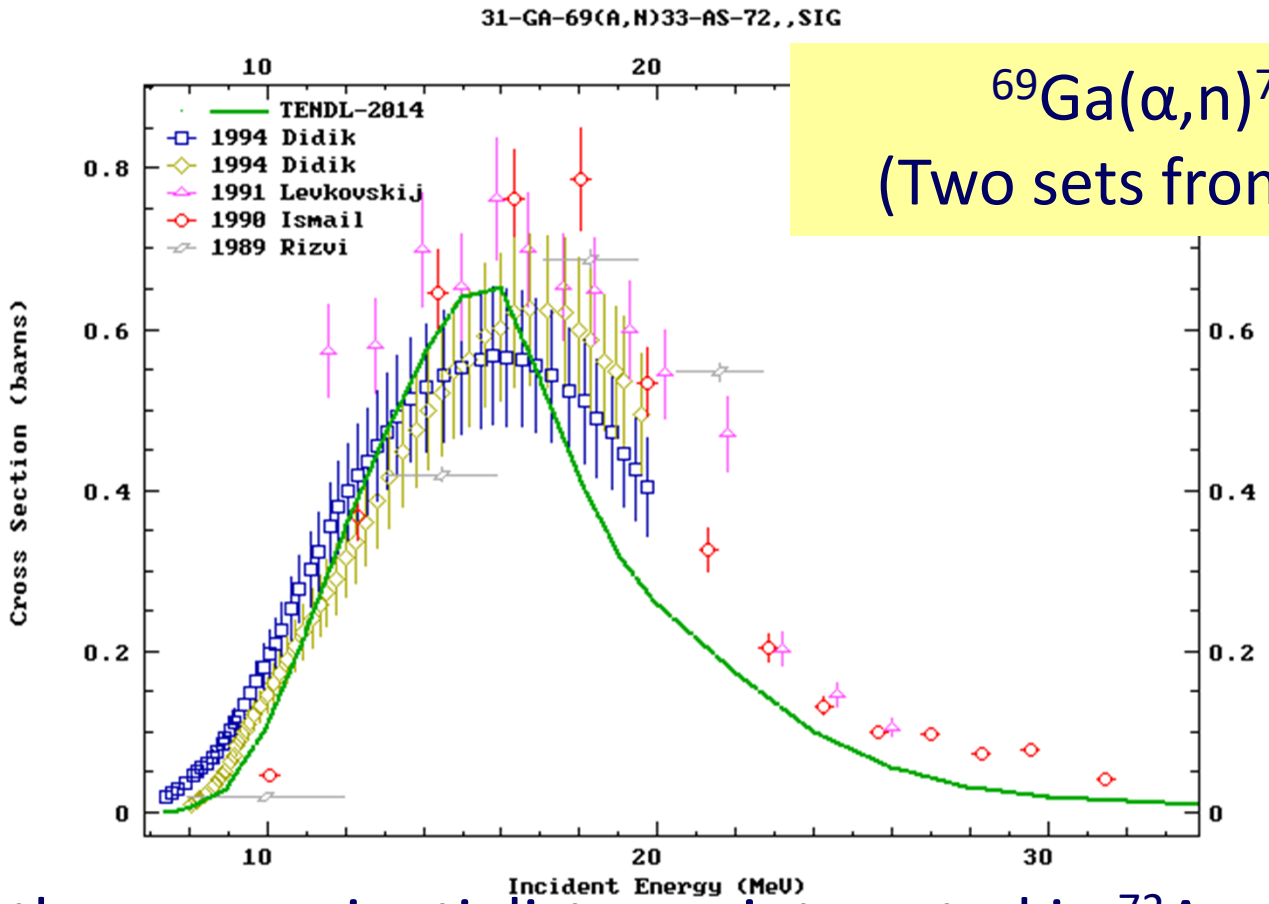
Rice absorb poisonous heavy metallic elements like Cd, As more than other vegetables.

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}As (26 hrs) Tracer Production

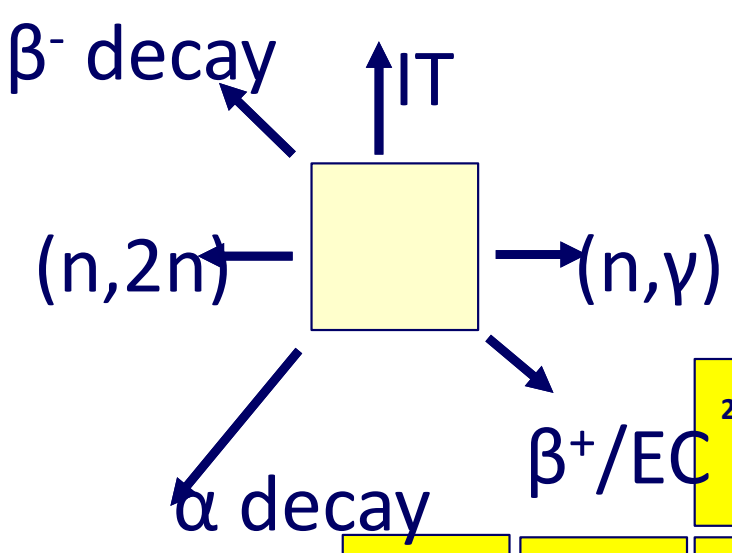


^{69}Ga(α,n)^{72}As
(Two sets from VECC)

- 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 Database for Reaction Network Study (in nuclear engineering)

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



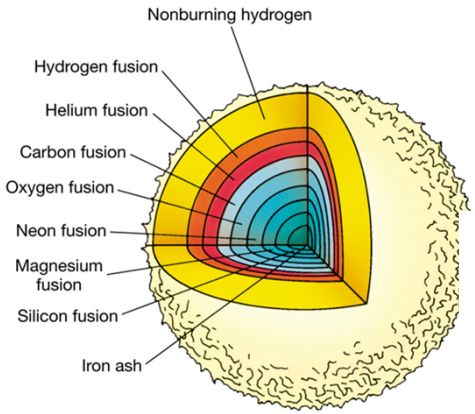
					^{242}Cm 163 d	^{243}Cm 29 y
					^{242}Am 16 h	
				^{241}Am 430 y	^{242m}Am 141 y	^{243}Am 7E+3 y
			^{238}Pu 88 y	^{239}Pu 2E+4 y	^{240}Pu 7E+3 y	^{241}Pu 14 y
			^{237}Np 2E+6 y	^{238}Np 2.1 d	^{239}Np 2.4 d	
^{234}U 2E+5 y	^{235}U 7E+8 y	^{236}U 2E+7 y	^{237}U 6.8 D	^{238}U 4E+9 y	^{239}U 24 min	

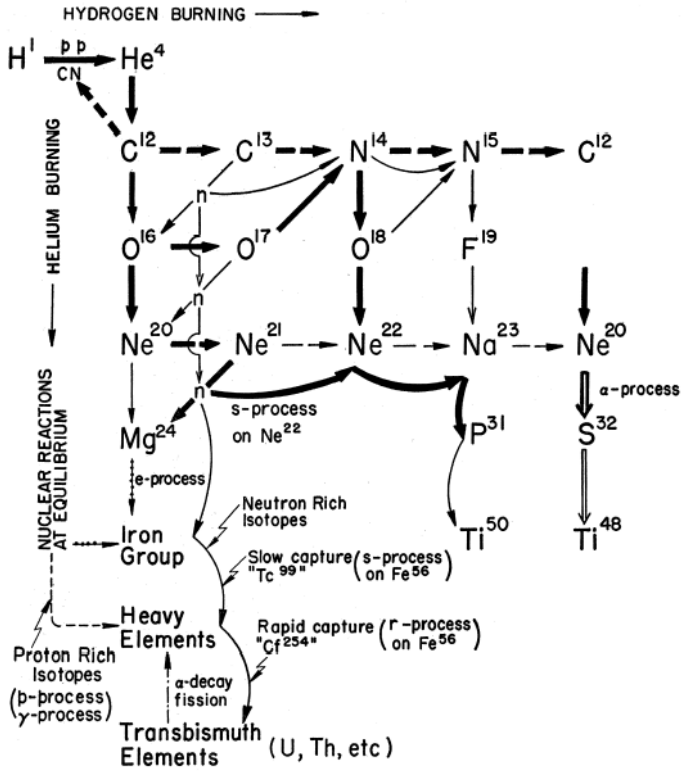
^{244}Cm 18 y	^{245}Cm 9E+3 y	^{246}Cm 5E+3 y	^{247}Cm 2E+7 y	^{248}Cm 3E+5 y		
^{244}Am 10 h						
^{242}Pu 4E+5 y	^{243}Pu 5 h					

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)





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

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

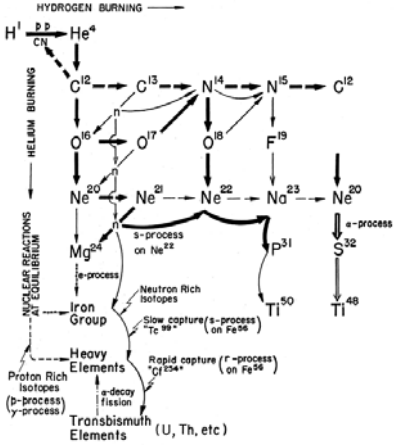
In the buildup of nuclei by the *s* and the *r* processes the reactions which govern both the rate of flow and the track followed in the (A,Z) plane are the (n,γ) and (γ,n) reactions, beta decay, and, at the ends of the tracks, alpha decay in the case of the *s* process and neutron-induced fission in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

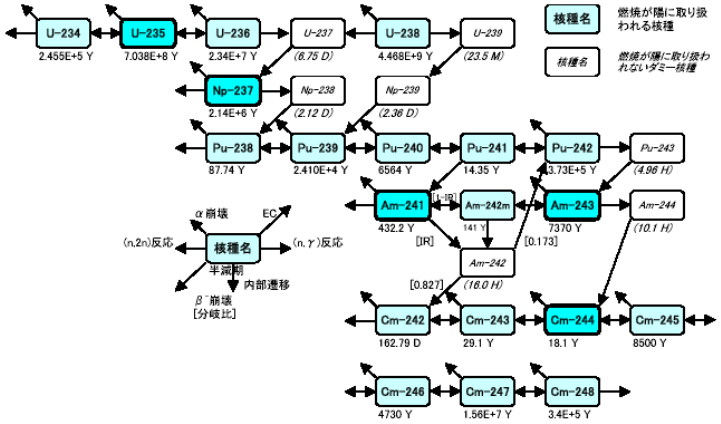
$$\lambda_n = 1/\tau_n = \sigma_n v_n n_n,$$
$$\lambda_\beta = 1/\tau_\beta = \text{const}/W_\beta{}^5, \qquad (8)$$
$$\lambda_\gamma = 1/\tau_\gamma = \sigma_\gamma c n_\gamma,$$

and σ_n and σ_γ are the cross sections for the (n,γ) and (γ,n) reactions, respectively; v_n and n_n are the velocity and density of neutrons responsible for the (n,γ) reactions; n_γ is the density of γ radiation; and W_β is the beta-decay energy.

Comprehensive nuclear data for reaction and decay are needed.

Nuclear Data in Bateman Equation





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

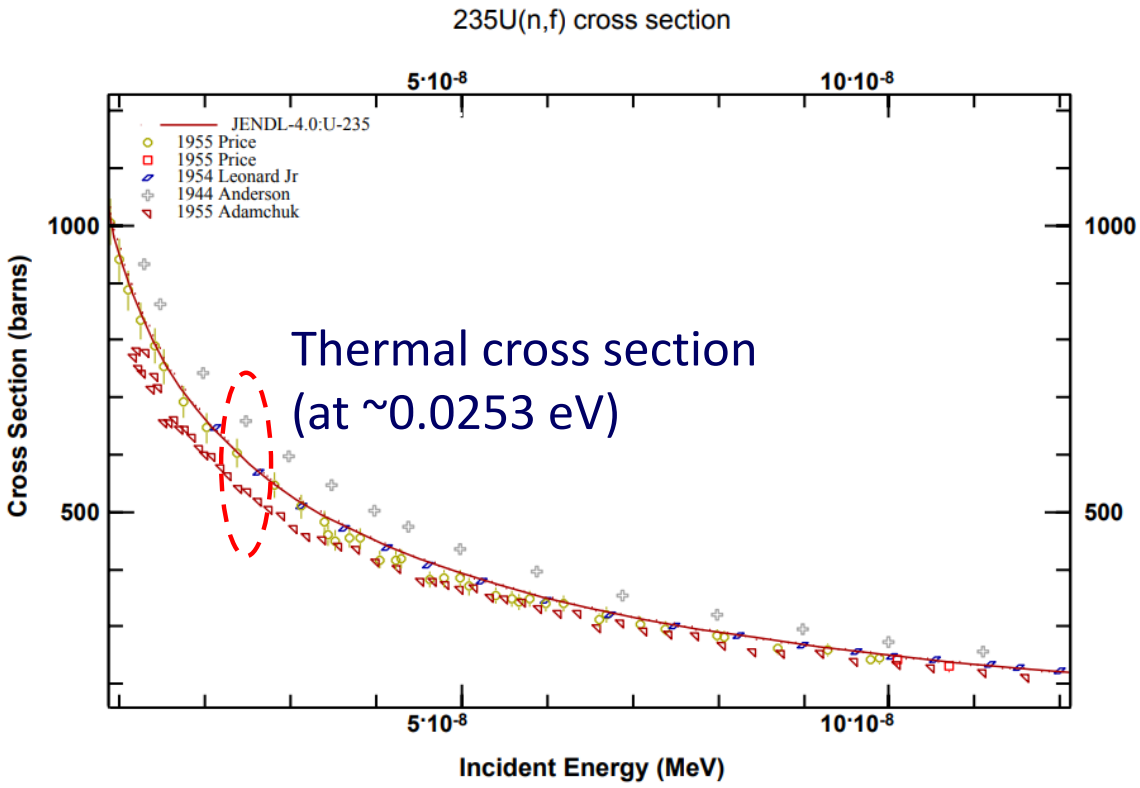
λ: decay constant (=ln 2/$T_{1/2}$)

σ: cross section

Collection of nuclear data is necessary. (nuclear database)

Nuclear Data in the 1950s – "Classified Information"

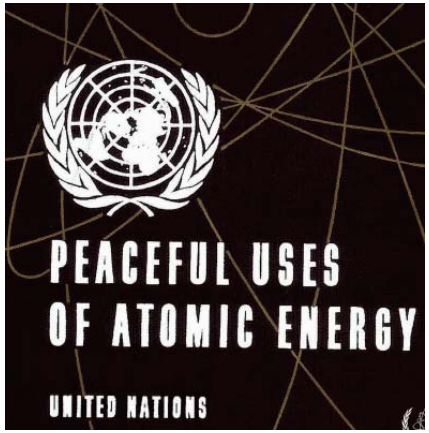
Nuclear data information was classified in the 1950s. Even $^{235}U(n_{th},f)$ cross section was not an well stablished constant.



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.

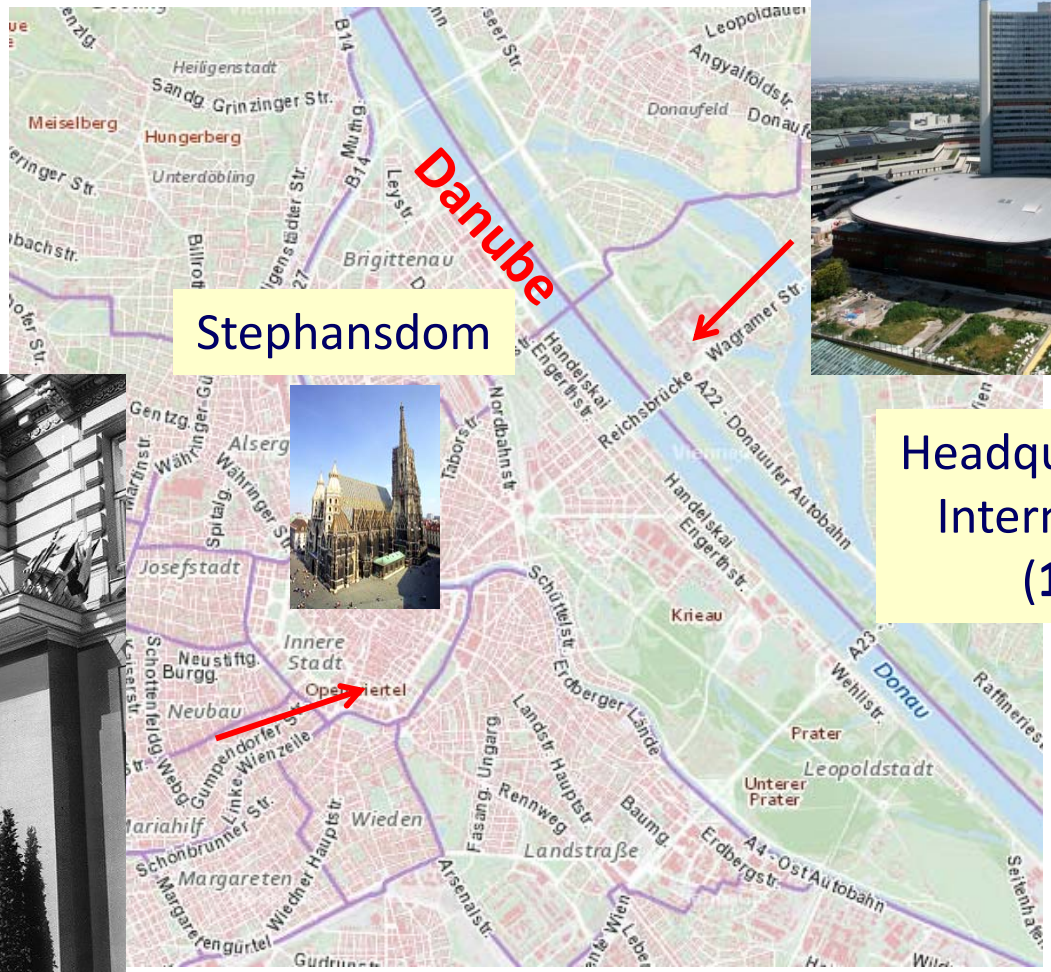


IAEA Nuclear Data Unit (1964)
IAEA Nuclear Data Section (1970)

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

Where is IAEA?

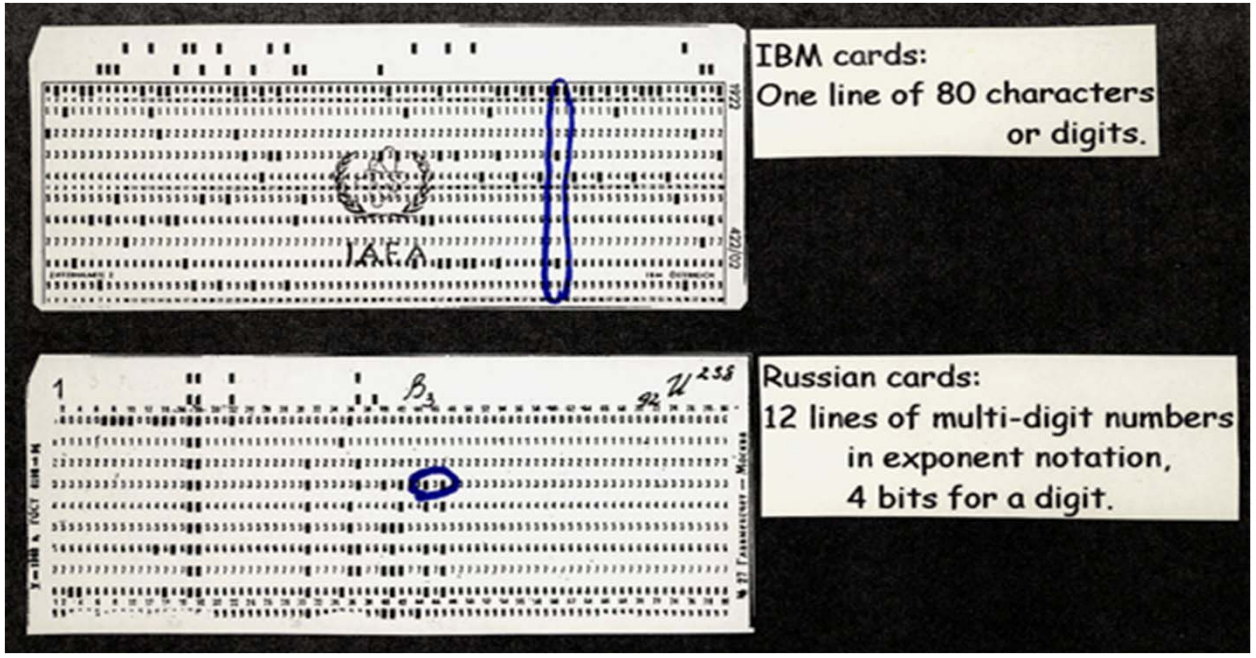
Headquarters on Kärntner Ring (**1958-1979**, now Grand Hotel)



Headquarters in Vienna International Centre (**1979- now**)

Data Exchange Between Western and Eastern Countries

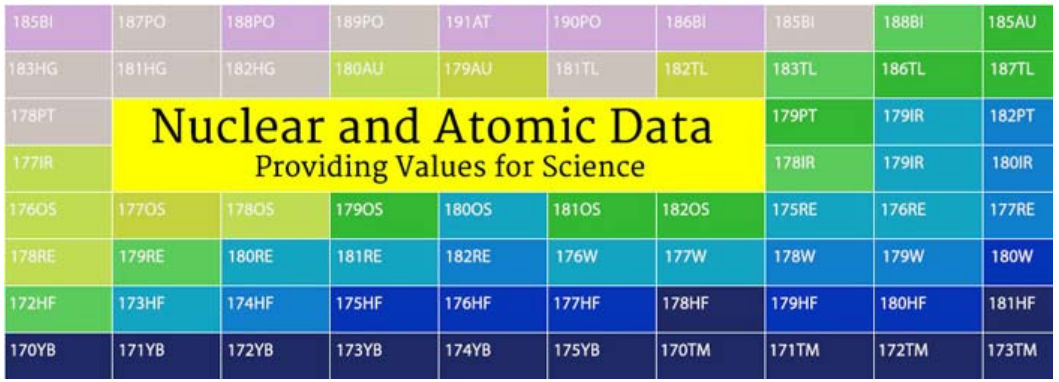
- Cards received from western and eastern countries. Same size, but different format.
- Nuclear Data Unit developed a special code which translate data in one card format to the other one.



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.

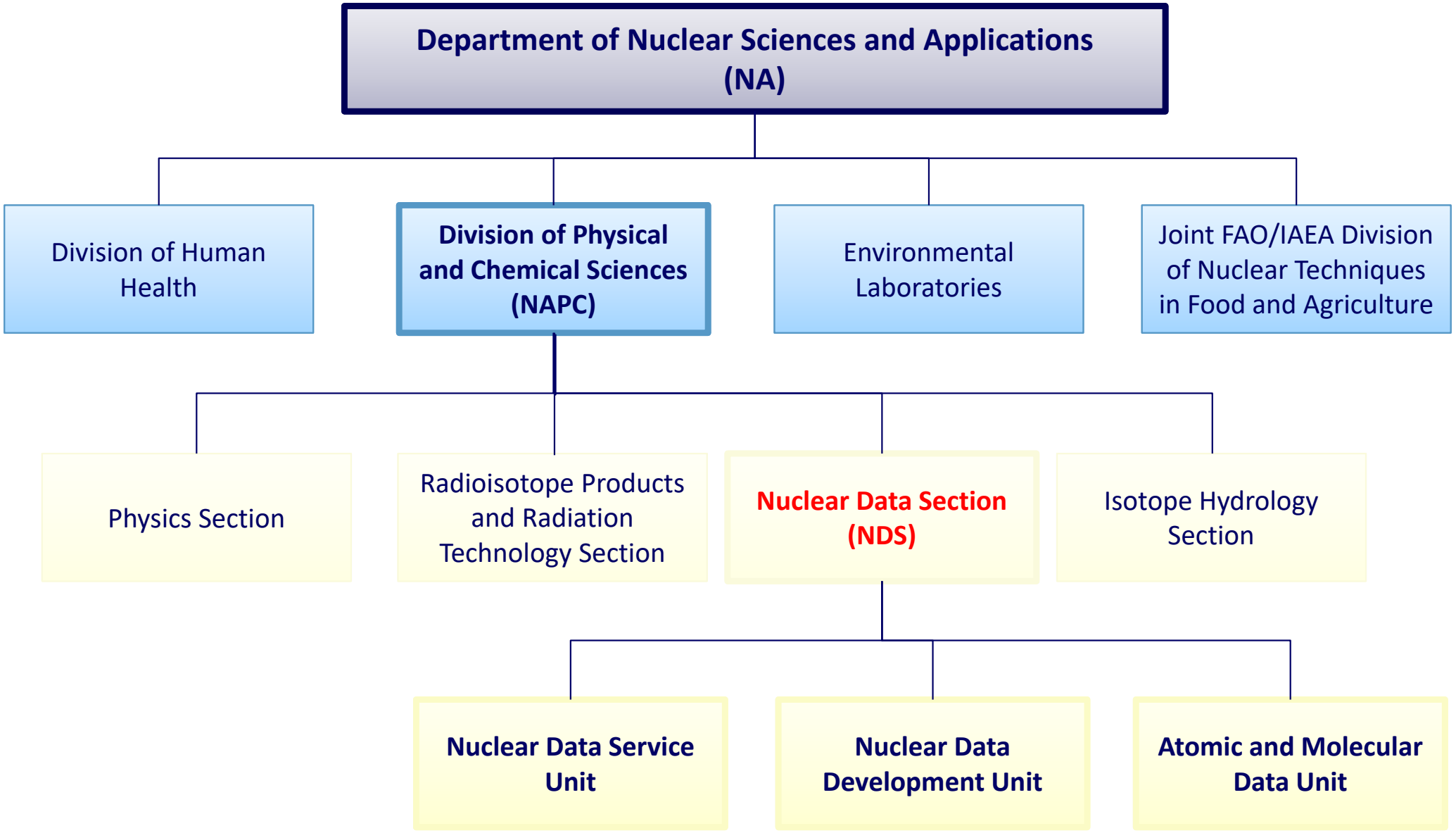
- Nuclear data for energy and non-energy application
  - Reactor (design, safety, spend fuel, decommissioning etc.)
  - Shielding
  - Dosimetry
  - Medical isotope production
  - Ion beam analysis
  - Safeguards
  - + Sciences (astrophysics etc.)



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:
Jean-Christophe Sublet

Software Engineer:
(Vecant)

Nuclear Data Physicist:
Naohiko Otsuka

Associate Nuclear Data Physicist:
Shin Okumura

Nuclear Data Services Assistant:
Lidija Vrapcenjak

Team Assistant:
Szende Elias

Nuclear Data Development Unit

Unit Head:
Roberto Capote Noy

Nuclear Physicist:
Paraskevi Demetriou

Nuclear Physicist:
Georg Schnabel

Team Assistant:
Kira Nathani

Atomic & Molecular Data Unit

Unit Head:
Christian Hill

Atomic Physicist:
Kalle Heinola

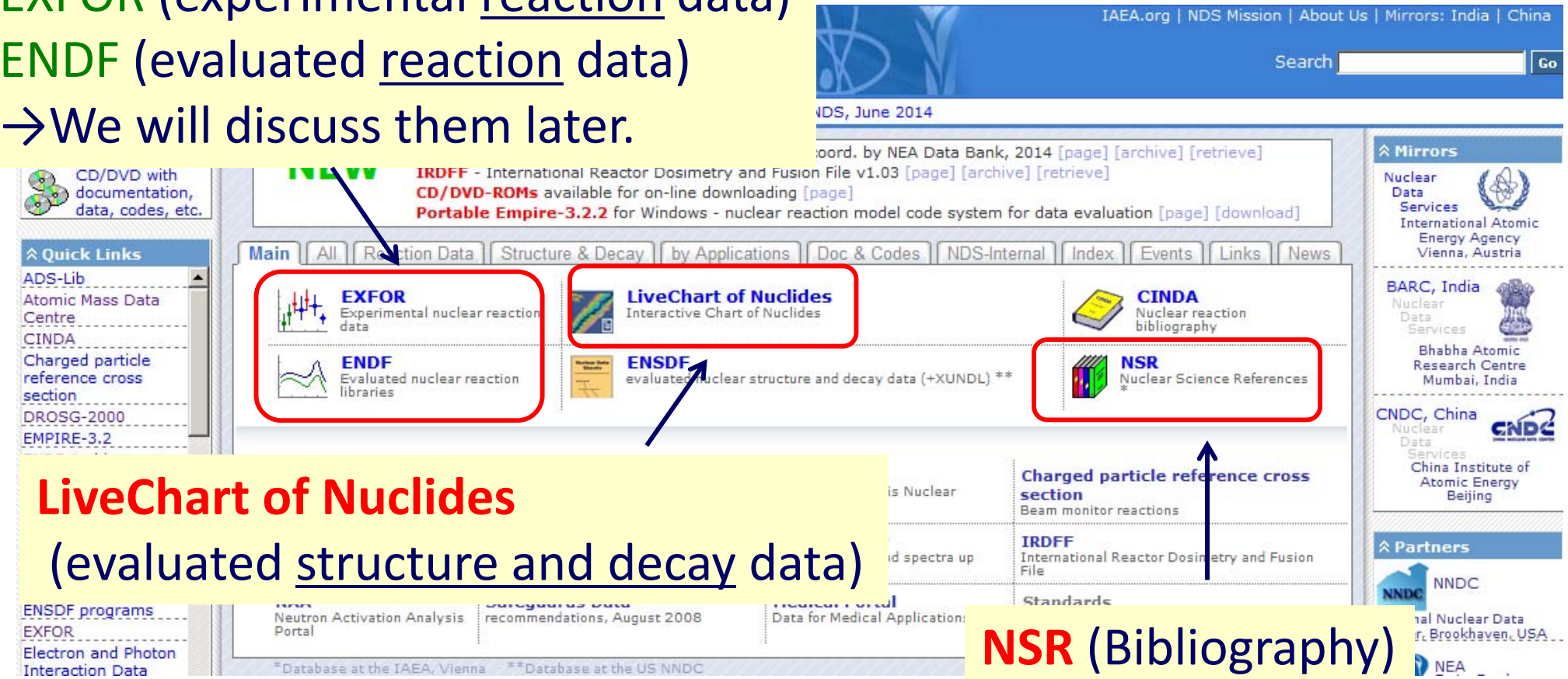
Nuclear Data Analyst/Programmer:
Marco Verpelli

IT Systems Engineer:
Ludmila Marian

12 professional staff and 4 supporting staff

IAEA Nuclear Data Services

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

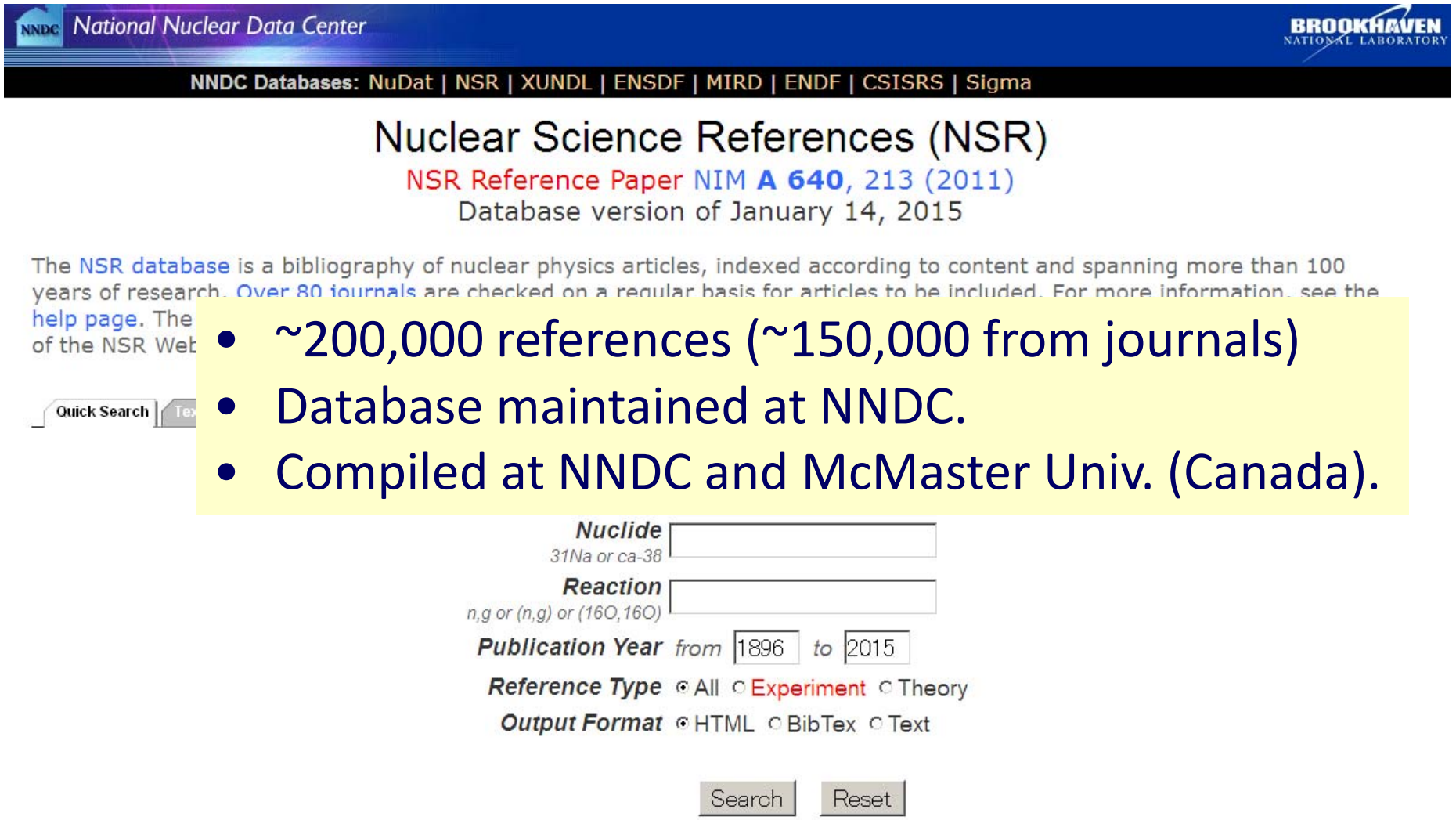


LiveChart of Nuclides
(evaluated structure and decay data)

NSR (Bibliography)

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

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



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

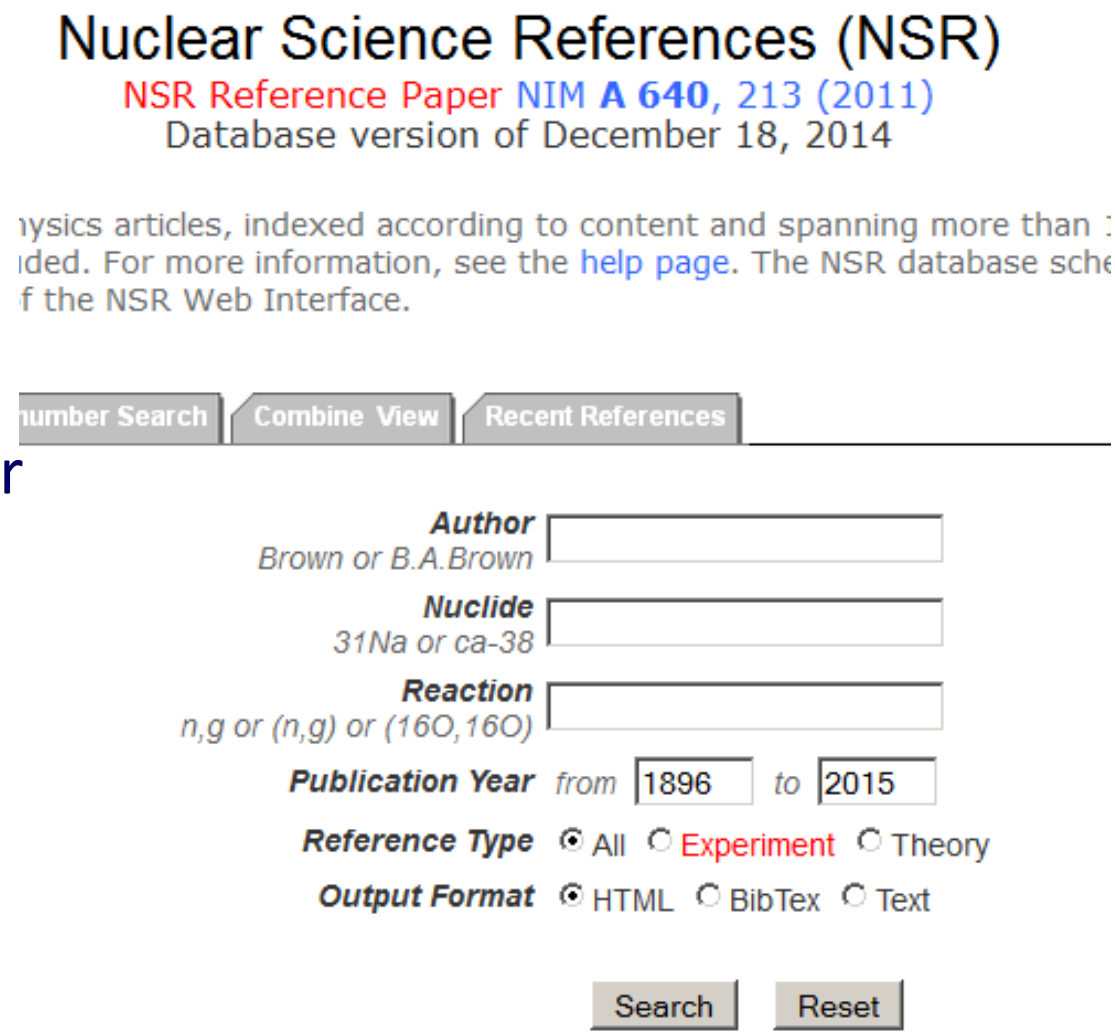
NSR (cont.)

Very easy to use!

Just provide

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

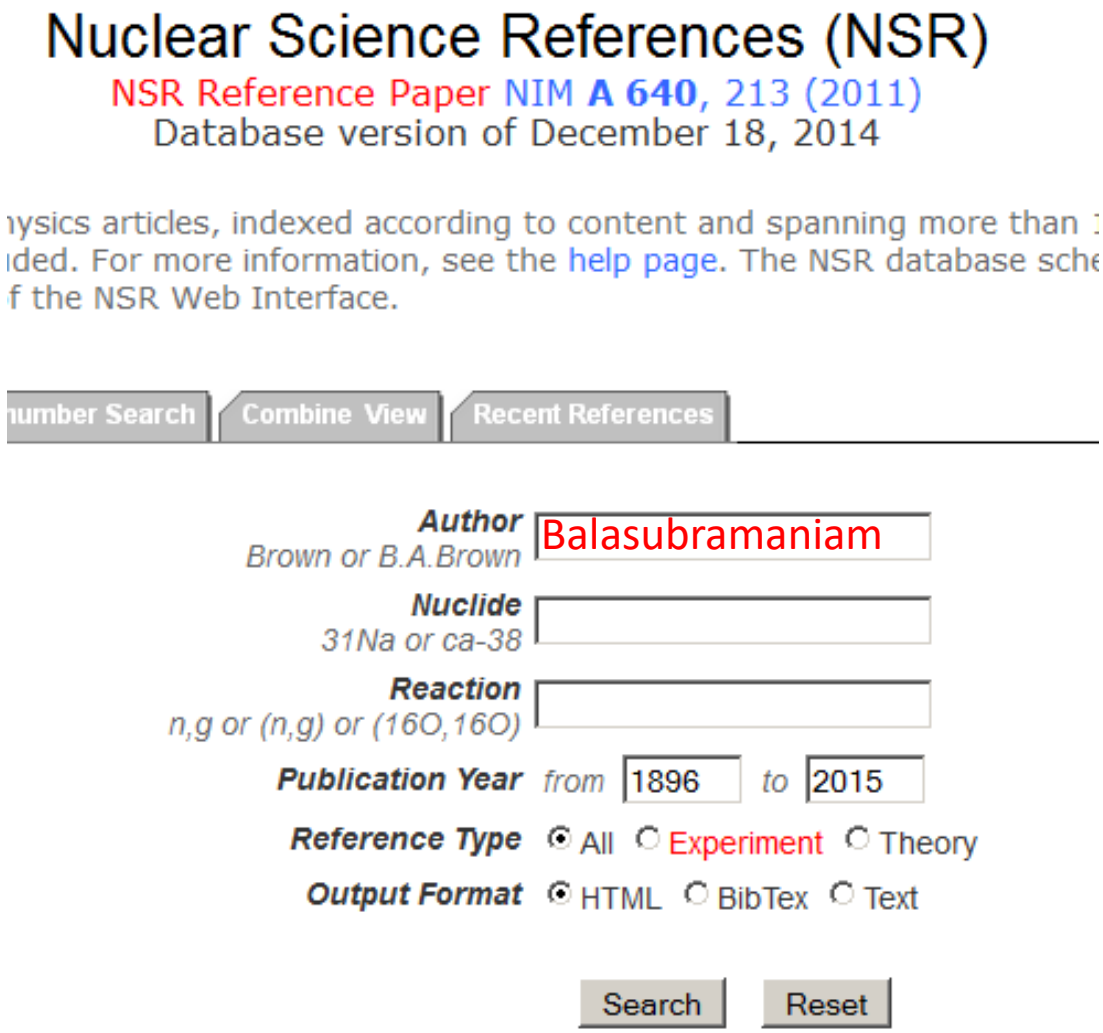
and search.



NSR – Exercise 1

Question

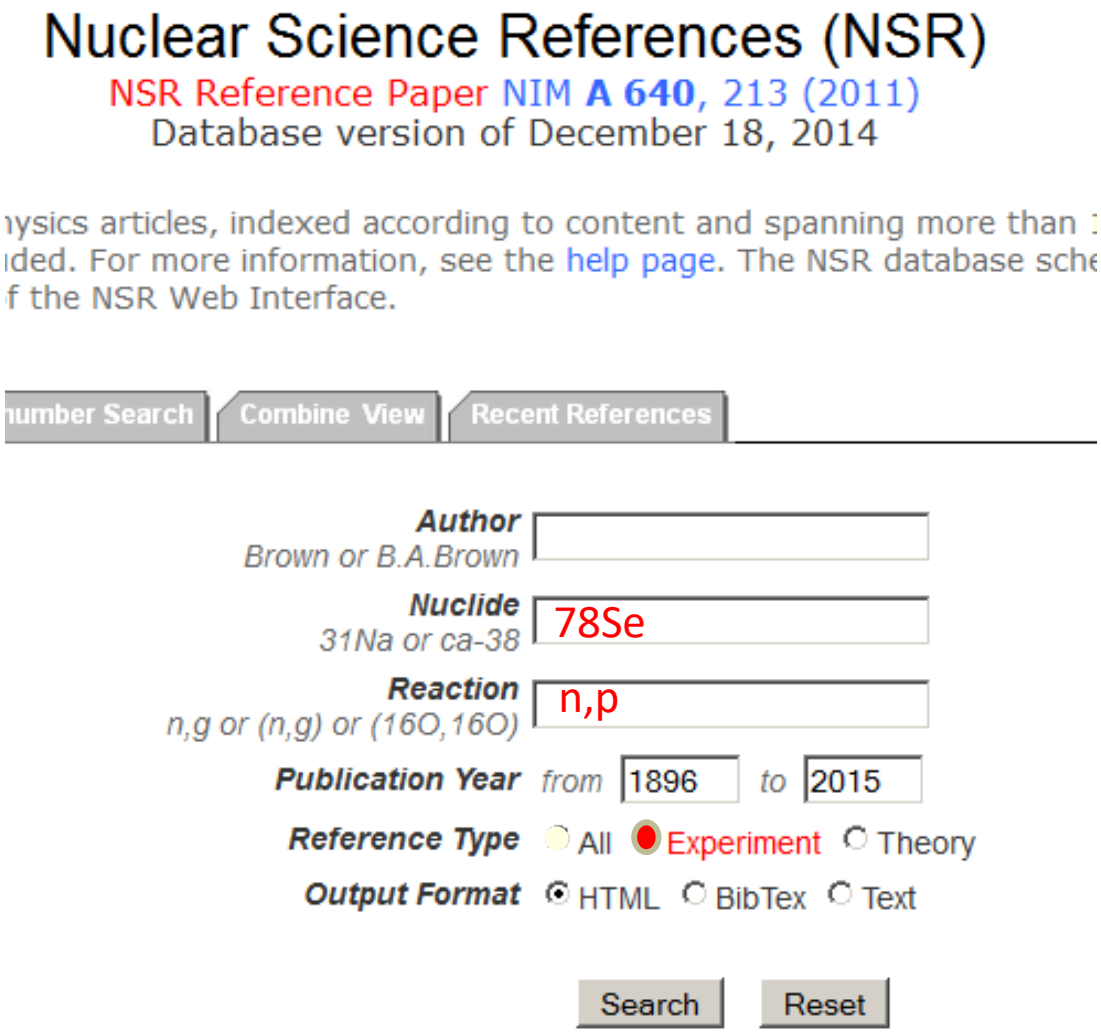
Search articles where "Balasubramaniam" is an author.



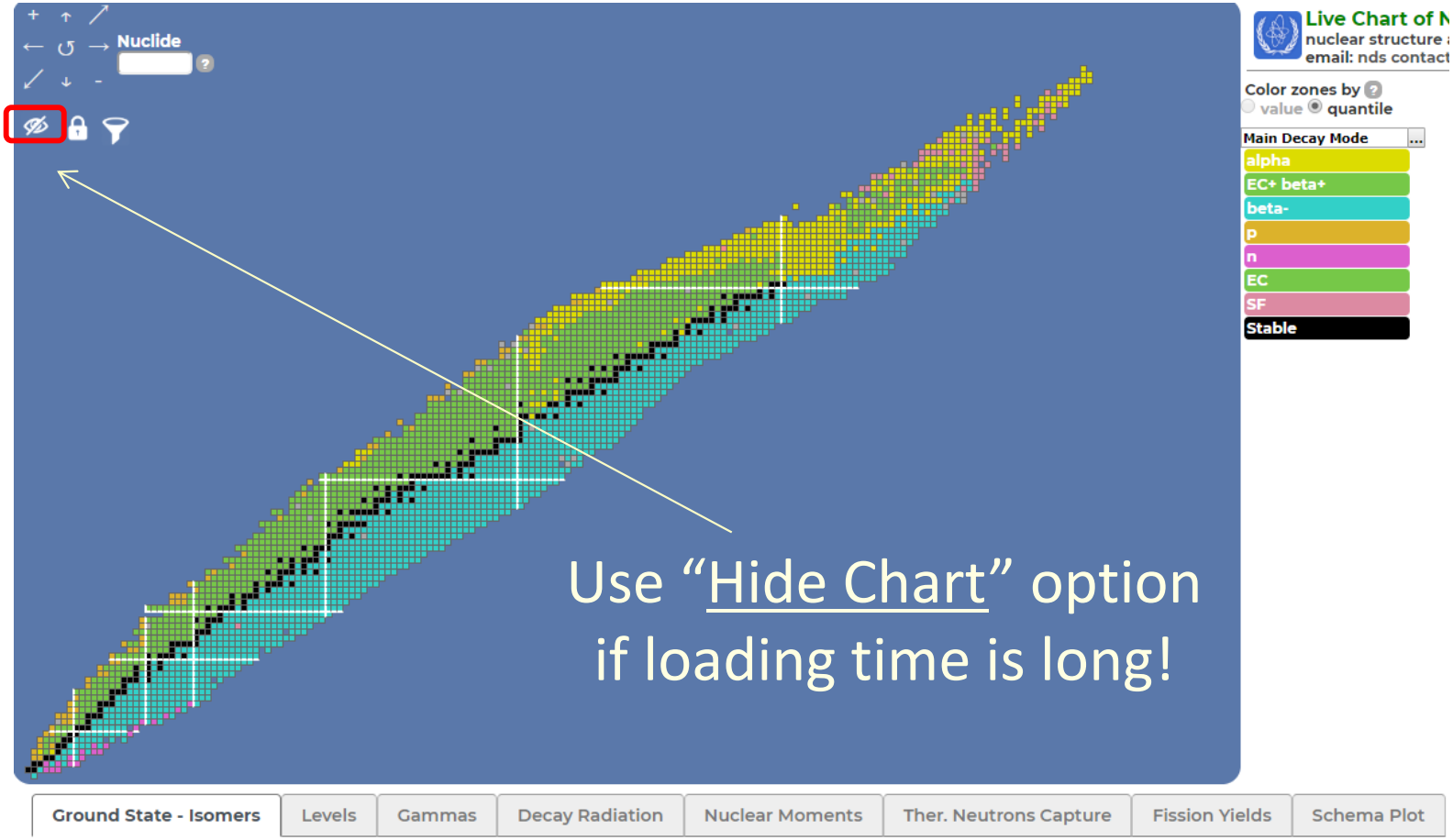
NSR – Exercise 2

Question

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

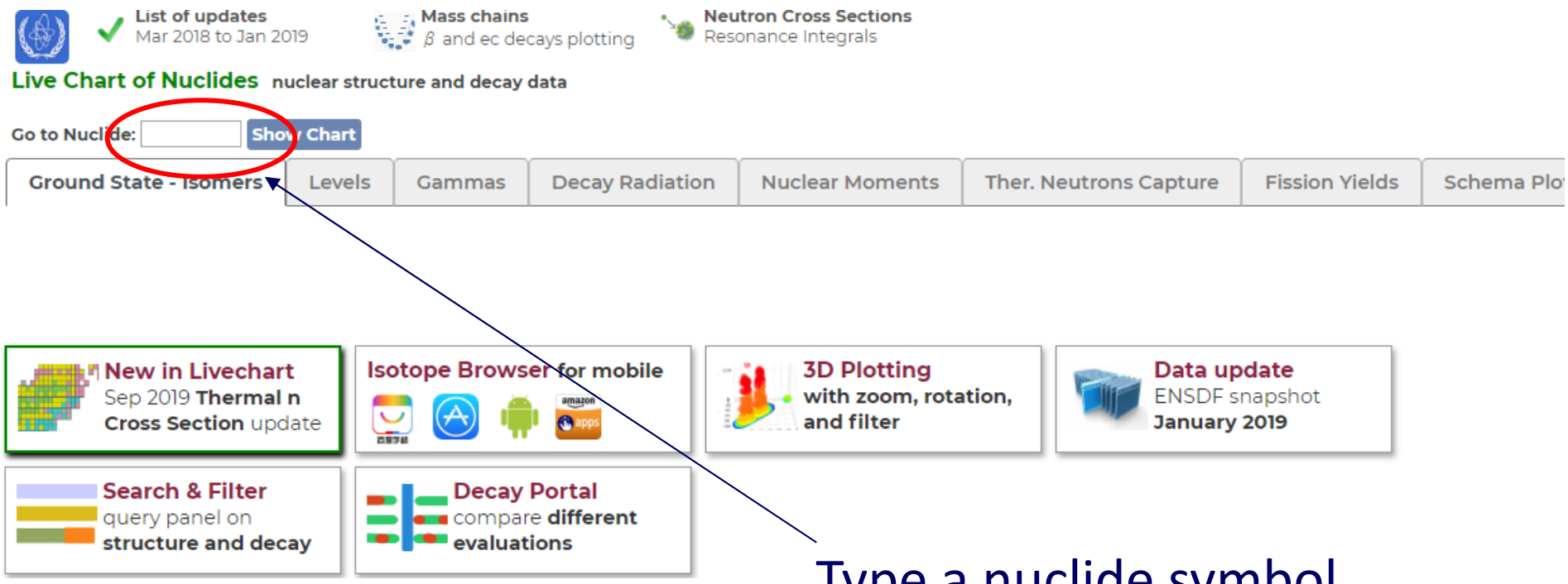


LiveChart of Nuclides
http://nds.iaea.org/livechart/



LiveChart of Nuclides (cont.)

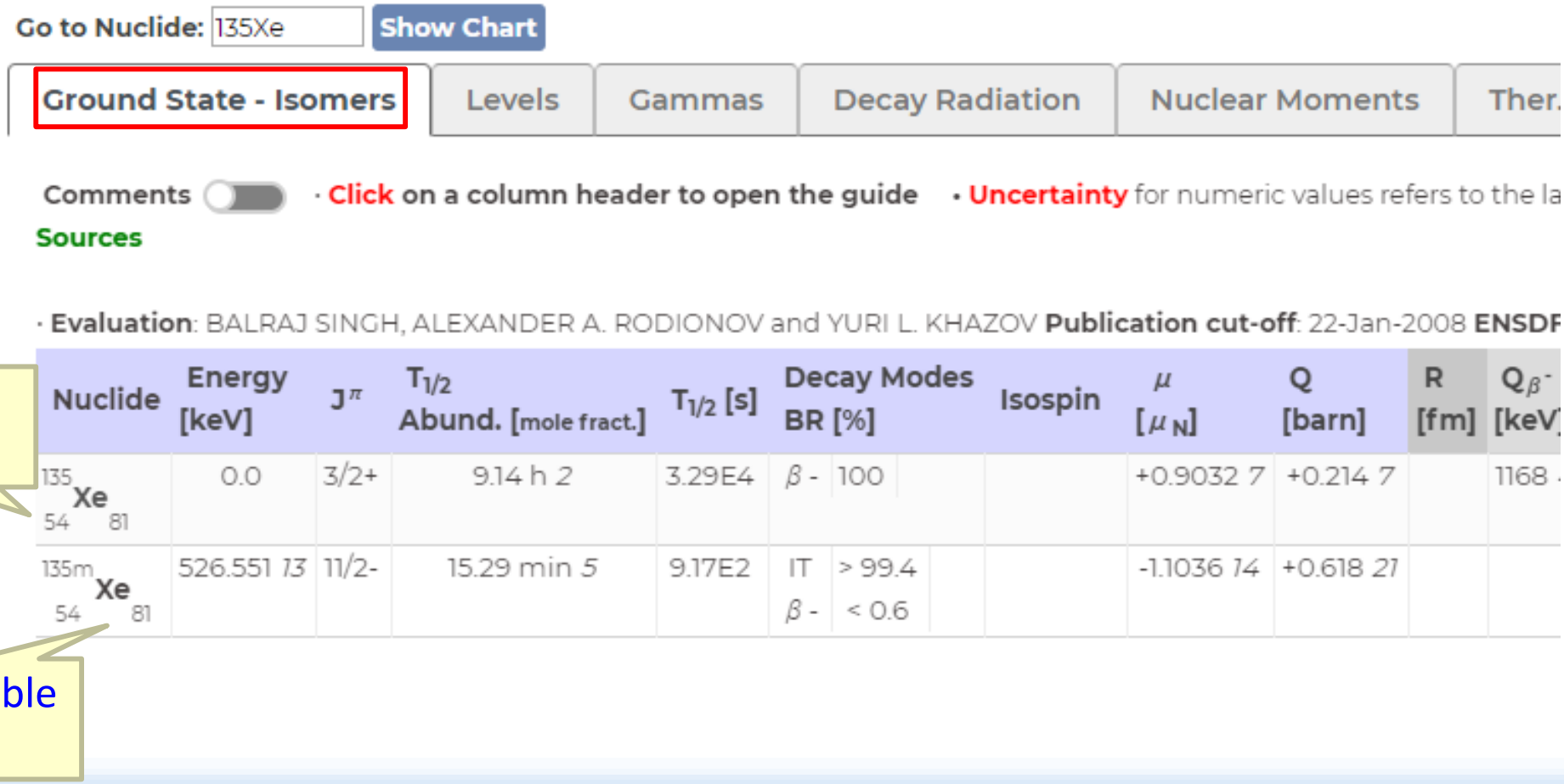
The query page becomes very simple if you select “Hide Chart” option.



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

LiveChart of Nuclides – ^{135}Xe

Ground State - Isomers tab



Go to Nuclide: 135Xe 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 la

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]
$^{135}_{54}Xe_{81}$	0.0	3/2+	9.14 h *2*	3.29E4	β -	100		+0.9032 *7*	+0.214 *7*		1168
$^{135m}_{54}Xe_{81}$	526.551 *13*	11/2-	15.29 min *5*	9.17E2	IT β -	> 99.4 < 0.6		-1.1036 *14*	+0.618 *21*		

Ground state

Metastable state

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

Levels tab

Go to Nuclide: 135Xe Show Chart

Ground State - Isomers | Levels | Gammas | Decay Radiation | Nuclear Moments | Ther. Neu

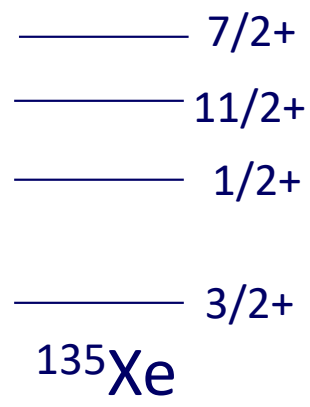
38 rows retrieved

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

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
$^{135}_{54}Xe_{81}$	0.0	3/2+		9.14 h *2*	3.29E4	β - 100		+0.9032 *7*	+0.214 *7*	
$^{135}_{54}Xe_{81}$	288.455 *15*	1/2+								
$^{135}_{54}Xe_{81}$	526.551 *13*	11/2-		15.29 min *5*	9.17E2	IT > 99.4 β - < 0.6		-1.1036 *14*	+0.618 *21*	
$^{135}_{54}Xe_{81}$	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

Go to Nuclide: 135Xe Show Chart

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

100% β- 9.14 h
•1 $^{135}_{54}Xe_{81} \Rightarrow {}^{135}_{55}Cs_{80}$

99.4% IT 15.29 min
•2 $^{135m}_{54}Xe_{81} \Rightarrow {}^{135}_{54}Xe_{81}$

0.6% β- 15.29 min
•3 $^{135m}_{54}Xe_{81} \Rightarrow {}^{135}_{55}Cs_{80}$

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]	Jp order	Decay	Q_{decay} note on Q value	Daughter	Comments	Total energy by ra Alpha	Beta
$^{135}_{54}Xe_{81}$	9.14 h *2*	0.0	3/2+	β - 100 %	1168 *4*	$^{135}_{55}Cs_{80}$		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 -

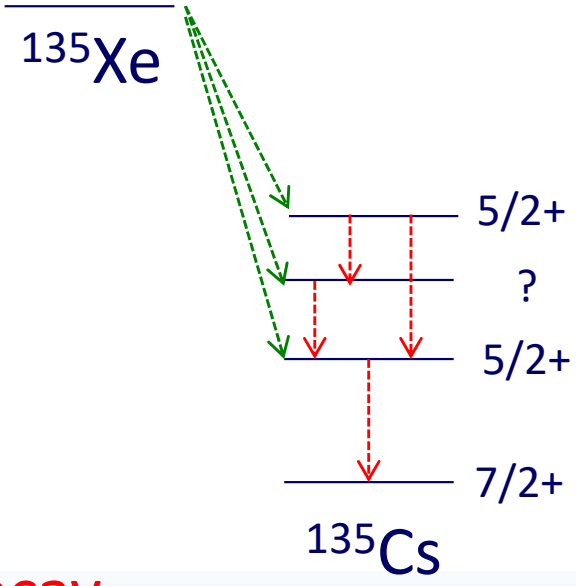
<E_β> [keV]	I_β-(abs) [%]	Daughter level [keV]	J^π	$E_{\beta^-,max}$ [keV]	log*ft*	Transition type	Comments
26.9 *11*	0.123 *6*	1062.420 *14*		(103)	5.71 *6*		
50.0 *12*	0.075 *5*	981.315 *22*		(184)	6.71 *5*		
173.3 *15*	3.11 *14*	608.186 *14*	5/2+	(557)	6.67 *3*	allowed	
248.1 *16*	0.59 *3*	407.989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

β-decay

Gamma

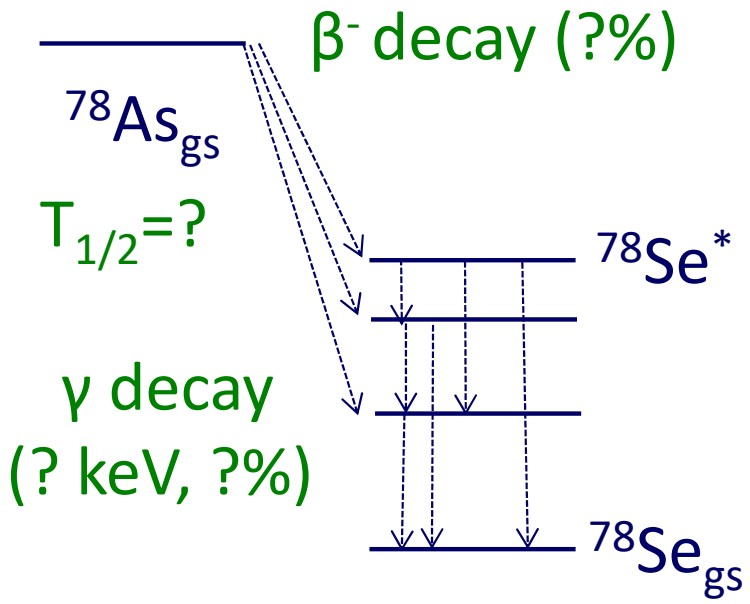
E_γ [keV]	I_γ-(abs) [%]	Initial level [keV]	J^π	Final level [keV]	J^π	Mult.	δ	α_T	Comments
158.197 *18*	0.289 *14*	407.989 *13*		249.793	5/2+				
200.19 *10*	0.012 *5*	608.186 *14*	5/2+	407.989					
249.794 *15*	**90 *3***	249.793 *12*	5/2+	0.0	7/2+	M1(+E2)	< 1.0	0.0737 *20*	
358.39 *3*	0.220 *11*	608.186 *14*	5/2+	249.793	5/2+	M1,E2		0.0265 *17*	

γ-decay



LiveChart of Nuclides - Exercise

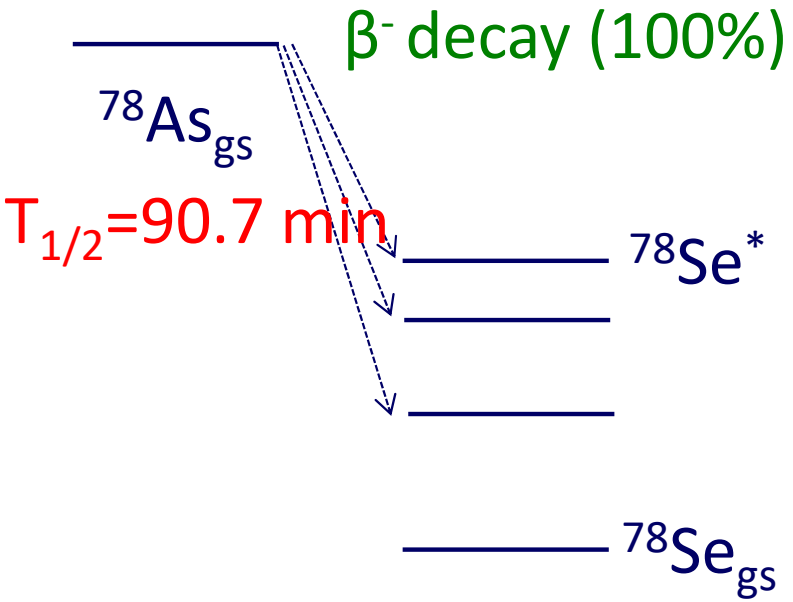
One determined the $^{78}Se(n,p)^{\mathbf{78}}\mathbf{As}$ cross section by detection of γ from ^{78}As - β^- decay → $^{78}Se^*$- γ decay→$^{78}Se_{gs}$.



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

Go to Nuclide: 78As Show Chart

Ground State - Isomers | Levels | Gammas | Decay Radiation | Nuclea

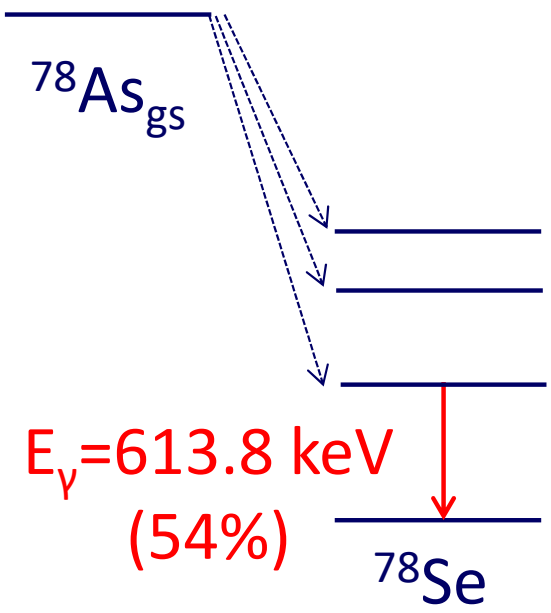
Comments · Click on a column header to open the guide · Uncertainty for nume

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 [barı
$^{78}_{33}As_{45}$	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: 78As Show Chart

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

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_γ [keV]	I_γ (abs) [%]	Initial level [keV]	J^π	Final level [keV]	J^π	Mult.	δ	α_T	Comments
156.6 *3*	0.092 *24*	2838.58 *9*	(2+)	2682.09	4+				
174.2 *3*	0.18 *4*	2682.09 *9*	4+	2507.72	3-				
351.1 *2*	0.162 *24*	1854.00 *9*	3+	1502.64	4+				
354.3 *2*	1.9 *3*	2682.09 *9*	4+	2327.34	2+				
391.0 *3*	0.124 *21*								
449.8 *4*	0.08 *3*	1758.91 *11*	0+	1308.66	2+				
462.2 *2*	0.59 *8*	3144.52 *13*	3-	2682.09	4+				
468.8 *3*	0.097 *19*								
497.0 *3*	0.18 *3*	1995.78 *10*	2+	1498.76	0+				
503.7 *2*	0.42 *6*	2838.58 *9*	(2+)	2334.87	0+				
545.3 *1*	3.0 *4*	1854.00 *9*	3+	1308.66	2+				
551.8 *3*	0.17 *4*								
613.8 *1*	**54 *6***	613.84 *7*	2+	0.0	0+				

ENSDF insertion: 2

Comments	Tota
	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)

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

We extracted these data from LiveChart.

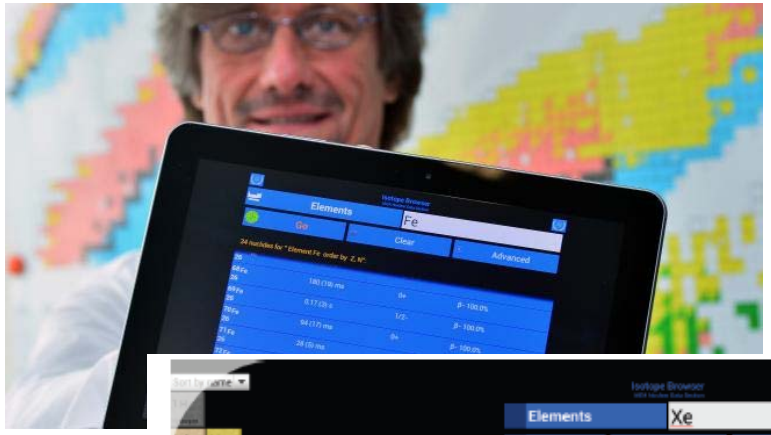
TABLE I. The decay data of the radioisotopes produced

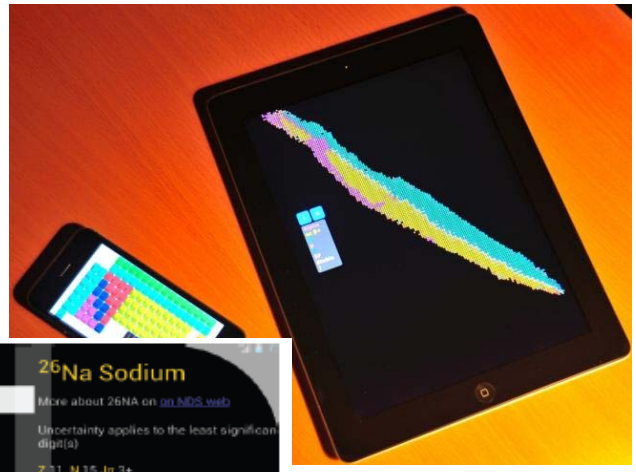
Nuclear Reaction	Abundance (%)	Half life	E_γ (MeV)	f_d (%)
^{78}Se$(n, p)^{78}$As	23.77 ± 0.28	90.7 ± 0.2 m	0.614	54 ± 0.6
^{80}Se$(n, p)^{80}$As	49.61 ± 0.41	15.2 ± 0.2 s	0.666	42 ± 0.5
^{56}Fe$(n, p)^{56}$Mn	91.75 ± 0.36	2.578 ± 0.0001 hr	0.847	99 ± 0.3
^{19}F$(n, p)^{19}$O	100	26.91 ± 0.08 s	0.197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

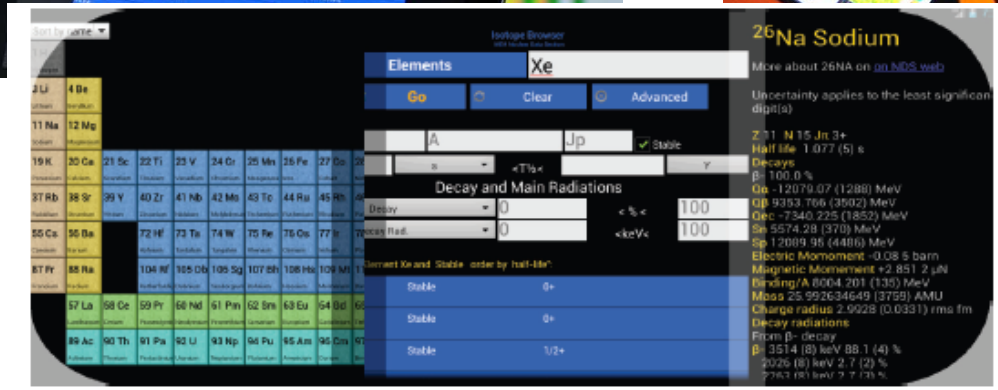
LiveChart of Nuclides – Data Source

- 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)!